PHYTOPATHOLOGY

VOLUME XIX, 1929

PHYTOPATHOLOGY

AN INTERNATIONAL JOURNAL

OFFICIAL ORGAN OF THE AMERICAN PHYTOPATHOLOGICAL SOCIETY

VOLUME XIX
JANUARY–DECEMBER, 1929

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Page 79, title, *read* to 31, 1928, inclusive, *for* 1928, to January 1, 1929.

Page 82, abstract 2, name, *read* A. H. Gilbert *for* G. H. Gilbert.

Page 84, line 6, *read* cowpea roots in 8 hours and within pineapple roots in 24 hours *for* roots in 8 hours.

Page 92, abstract 1, line 5, *read* externally *for* internally.

Page 94, abstract 1, line 12, *omit* in case of Verticillium wilt.

Page 108, line 2, *read* acetone *for* acetate.

Page 144, Table 1, column 1, last line, *read* (Fr.) Ces. *for* Sor.; column 2, *read* ..... *for* 5th do and 6th do; column 3, *read* ..... *for* 2d do and 3d do; column 4, *read* ..... *for* each do.

Page 147, paragraph 1, line 13, *read* headblight *for* hedblight.

Page 163, title, *read* Disease *for* Diease.

Page 171, paragraph 4, line 10, *read Sclerotium for Sclerotinia.*

Page 172, footnote, *read* D. T. Killough *for* D. J. Killough.

Page 173, paragraph 1, line 1, *read* reveal *for* reval.

Page 318, line 1, *read* bowed *for* booked.

Page 352, paragraph 3, line 4, *read* VI *for* I.

Colored plate (opp. page 366) *read* VI *for* 1.

Page 443, paragraph 2, line 9, *read* re-sorted *for* restored.

Page 479, line 13, *after* Virginia *add* and Illinois as reported by Anderson (Phytopathology **14**: 31. 1924).

Page 565, line 9, *read* Mc Rae *for* McRea.

Page 570, line 6, *read* neighbor *for* neighboring.

Page 572, paragraph 2, line 9, *read* or *for* of.

Page 624, paragraph 1, line 13, *read* 9, *a, for* 10, *a.*

Page 682, paragraph 1, line 1, *read* Turkey (*T. vulgare*) *for* Velvet Don (*T. durum*); figure legend, *read* Turkey (*T. vulgare*) *for* Velvet Don (*T. durum*); paragraph 2, line 1, *read* Velvet Don (*T. durum*) for Turkey (*T. vulgare*).

Page 683, figure 3 legend, *read* Velvet Don (*T. durum*) *for* Turkey (*T. vulgare*).

Page 742, paragraph 2, line 11, *read* and then *for* and the.

Page 872, paragraph 3, line 2, *read garryana for garyana.*

September, October, and November issues, first printed page, line 4 under Associate Editors, *read* Agricultural Experiment Station, Gainesville, Fla., *for* Tobacco Experiment Station, Quincy, Fla.

Plate XXXIV (opp. page 932), *read* 600 *for* 1600.

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Page 965, line 6, *read* very *for* vary.

Page 966, paragraph 5, line 1, *read* Sclerosporas *for* Sclerospora.

Page 967, line 8, *read* far *for* fas.

Page 972, last line, *read* Mycosphaerella *for* Myosphaerella.

Page 973, paragraph 7, line 2, *change* blue to green.

Page 1019, paragraph 3, line 2, *read* Sirexcipulina *for Sirex cipulina.*

Page 1021 line 4, *read* apothecial *for* apothetical.

Page 1042, paragraph 1, line 5, *after* infection *insert* of.

Pages 1033, 1035, running heads, *after* beet *add* curly top.

December issue, first printed page, line 4 under Associate Editors, *after* Station *insert* comma.

Page 1073, paragraph 3, line 4, *read* attached *for* atached.

Page 1086, footnote, line 4, *after* times *insert* while.

Page 1121, paragraph 2, line 3, *read* bodies *for* boidies.

Page 1135, abstract, title, *read terrestris for terrestria.*

Page 1136, line 3, *read* terrestris *for* terrestria.

Page 1141, abstract 2, line 4, *read* power to infect and produce severe symptoms *for* infection power and the development of severe symptoms.

CONTENTS OF VOLUME XIX

NO. 1. JANUARY

PAGE

The relation of weather to the development of stem rust in the Mississippi valley. EDMUND B. LAMBERT 1

A new virus disease epidemic on onions. I. E. MELHUS, C. S. REDDY, W. J. HENDERSON, and EDGAR VESTAL 73

Abstracts of papers presented at the twentieth annual meeting of the American Phytopathological Society, New York, N. Y., December 28 to 31, 1928, inclusive 79

NO. 2. FEBRUARY

The peach aphid (Myzus persicae Sulz.) as an agent in virus transmission. ISMÉ A. HOGGAN 109

White spot of alfalfa and its relation to irrigation. B. L. RICHARDS 125

Physiologic specialization in Fusarium spp. causing head blight of small grains. CHIH TU 143

The influence of temperature on the frequency of mutation in Helminthosporium sativum. J. J. CHRISTENSEN 155

Brooming disease of black locust (Robinia pseudacacia). CARL HARTLEY and FERDINAND W. HAASIS 163

A method of inoculation for Phymatotrichum root-rot investigations. J. J. TAUBENHAUS, B. F. DANA, W. N. EZEKIEL, W. J. BACH, and J. P. LUSK 167

Phytopathological Notes 171

Book Review 177

NO. 3. MARCH

An Actinomycete the cause of soil rot or pox in sweet potatoes. J. F. ADAMS 179

Monograph of the genus Pestalotia de Notaris. E. F. GUBA 191

The effect of the H-ion concentration of the culture solution on the behavior of Fusarium chromyophthoron and Allium cepa and the development of pink-root-disease symptoms. C. P. SIDERIS 233

Some observations upon the white pine blister rust in New York. WALTER H. SNELL 269

Bordeaux spray in the control of fire blight of apple. MONROE MCCOWN 285

Viability of certain plant pathogenes in soils. M. K. PATEL 295

A comparative study of Sclerotinia minor Jagger and Sclerotiniá intermedia Ramsay in culture. A. H. CHIVERS 301

A mosaic disease of the Easter lily. LAWRENCE OGILVIE and CARL E. F. GUTERMAN 311

Phytopathological Notes 317

NO. 4. APRIL

Mark Alfred Carleton, 1866–1925. E. M. FREEMAN 321

Experiments with repeating pine rusts. E. P. MEINECKE 327

Pokkah-bong and twisted-top diseases of sugar cane in Cuba. C. N. PRIODE 343

Rhizidiocystis ananasi Sideris, nov. gen. et sp., a root hair parasite of pineapples. C. P. SIDERIS 367

The development of soil rot of tomatoes during transit and marketing. G. B. RAMSEY and ALICE ALLEN BAILEY 383
The occurrence of Sclerospora graminicola on maize in Wisconsin. WM. H. WESTON, JR. 391
A scale for measuring areas of Ribes leaves. ROBERT S. CARUTHERS 399
Root-observation boxes. A. L. DEAN 407
Titles and abstracts of papers read at the tenth annual meeting of the Canadian Division of the American Phytopathological Society, Guelph, Ontario, December 20 and 21, 1928 413

NO. 5. MAY

Studies in the physiology and cytology of Ustilago zeae and Sorosporium reilianum. W. F. HANNA 415
Sporotrichum fruit spot and surface rot of apple. MAX W. GARDNER 443
Cronartium comptoniae Arth. in western North America. H. G. LACHMUND 453
Ecological studies of curly top of sugar beets. WALTER CARTER 467
Nematospora on pomegranates, citrus, and cotton in California. HOWARD S. FAWCETT 479
A progress report on the control of crown gall, hairy root, and other malformations at the unions of grafted apple trees. A. J. RIKER, G. W. KEITT, and W. M. BANFIELD 483
Plant quarantines and the State. W. A. MCCUBBIN 487
Some present-day problems. H. P. BARSS 493
The second decade of the American Phytopathological Society. R. J. HASKELL 503
Phytopathological Notes 507
Report of the twentieth anniversary meeting of the American Phytopathological Society 511
Minutes of the field meeting of the Southern Section of the American Phytopathological Society, July 11–13, 1928 531

NO. 6. JUNE

Physiological strains of Alternaria solani. REINER BONDE 533
Relation of species of Pythium to the root-rot disease of sugar cane. C. W. EDGERTON, E. C. TIMS, and P. J. MILLS 549
Plot arrangement to distribute neighbor influence in field trials. CARL HARTLEY 565
Dasyscypha fusco-sanguinea Rehm on western white pine, Pinus monticola Dougl. C. R. STILLINGER 575
Rhizoctonosis of Lobelia. S. C. TENG 585
False smut of maize, Ustilaginoidea. R. J. HASHELL and W. W. DIEHL 589
A method of testing the keeping quality of certain small fruits. NEIL E. STEVENS 593
Blue-staining fungi found in the United States. CAROLINE T. RUMBOLD 597
Another anthracnose of raspberry. S. M. ZELLER 601
Phytopathological Notes 605
Book Review 609

NO. 7. JULY

A destructive root disease of pineapples and other plants due to **Tylenchus brachyurus**, n. sp. G. H. GODFREY 611
Sulphur dusting for the prevention of stem rust of wheat. E. B. LAMBERT and E. C. STAKMAN 631

Diseases of economic plants in Peru. E. V. ABBOTT 645
The response of hulless barley to seed treatment for covered smut and stripe disease. R. H. PORTER, T. F. YU, and H. K. CHEN 657
A leaf spot of sycamore caused by Stigmina platani (Fuckel) Sacc. C. A. APOSTOLIDES 667
The life history of Sphaceloma ampelinum de Bary. C. L. SHEAR 673
The effect of Tilletia caries (DC.) Tul. (T. tritici (Bjerk.) Wint.) on the development of the wheat ear. W. A. R. DILLON WESTON, M.A. 681
Phytopathological Notes 687

NO. 8. AUGUST

Etiology of the pink-root disease of onions. H. N. HANSEN 691
Lentinus lepideus Fr.: A cause of heart rot of living pines. W. W. WAGENER 705
The use of acidulated mercuric chloride in disinfecting potato tubers for the control of Rhizoctonia. J. G. LEACH, H. W. JOHNSON, and H. E. PARSON 713
A butt-rot of balsam fir caused by Polyporus balsameus Pk. ERNEST E. HUBERT 725
The black mold of onions, caused by Aspergillus niger v. Tiegh. J. E. MACHACEK 733
Studies on the mycelium of Cronartium comptoniae Arthur on Pinus sylvestris L. W. G. HUTCHINSON 741
A root and butt-rot of conifers caused by Polyporus circinatus Fr. ERNEST E. HUBERT 745
Inactivation of the tobacco-mosaic virus by high pressures. N. J. GIDDINGS, H. A. ALLARD, and B. H. HITE 749
Phytopathological Note 751

NO. 9. SEPTEMBER

Studies on the variability and dissociations in the genus Fusarium. LEON H. LEONIAN 753
Observations on Armillaria root rot of orchard trees. LEROY CHILDS and S. M. ZELLER 869
The effect of grafting on resistance and susceptibility of beans to Colletotrichum lindemuthianum. J. G. LEACH 875
Phytopathological Notes 879

NO. 10. OCTOBER

Tōji Nishida, 1874–1927. R. KENT BEATTIE 881
Pathogenicity and cultural behavior of Ustilago zeae (Bekm.) Ung. from different localities. A. H. EDDINS 885
Host range and life-history studies of some leguminous Ascochytae. RODERICK SPRAGUE 917
Masking of sweet-potato mosaic. L. L. HARTER and W. A. WHITNEY 933
The effect of Bordeaux mixture on the internal temperature of potato leaflets. PAUL E. TILFORD and CURTIS MAY 943
The value of physiologic-form surveys in the study of the epidemiology of stem rust. E. C. STAKMAN, M. N. LEVINE, and J. M. WALLACE 951
A new Sclerospora from Fiji. WILLIAM H. WESTON, JR. 961
Plant-disease notes from the Central Andes II. RAFAEL A. TORO 969
Attenuation of curly-top virus by resistant sugar beets which are symptomless carriers. C. F. LACKEY 975

NO. 11. NOVEMBER

The history and distribution of Phomopsis pseudotsugae in Europe. MALCOLM WILSON and GLENN GARDNER HAHN 979
Septoria acicola and the brown-spot disease of pine needles. GEORGE G. HEDGCOCK 993
The relation of lime-sulphur sprays to the abscission of young apples. F. S. HOWLETT and CURTIS MAY 1001
Is the aster-yellows virus detectable in its insect vector? IRENE D. DOBROSCKY 1009
Life history and pathological aspects of Godronia cassandrae Peck (Fusicoccum putrefaciens, Shear) on cranberry. C. L. SHEAR and HENRY F. BAIN 1017
Airplane photography in the study of cotton root rot. J. J. TAUBENHAUS, WALTER N. EZEKIEL, and C. B. NEBLETTE 1025
A new host of sugar-beet curly top. RUTH COLVIN STARRETT 1031
Storage rots of cranberries in the 1928 crop. NEIL E. STEVENS and HENRY F. BAIN 1037
Stem rust of wheat in Peru. E. V. ABBOTT 1041
Relation of time of roguing to the spread of spindle tuber in seed-potato plate. H. O. WERNER 1045
Coleodictyospora, a new genus of Dematiaceae. VERA K. CHARLES 1051

NO. 12. DECEMBER

Ralph Cleon Thomas, 1892–1928. S. A. WINGARD 1057
A study of the biology of a new spore-forming Rhizoctonia, Corticium praticola. JOHN E. KOTILA 1059
Experiments with bluestain fungi in southern pines. RALPH M. NELSON and J. A. BEAL 1101
A new Sclerospora from Australia. WILLIAM H. WESTON, JR. 1107
Certain early developmental phases common to many fungi. G. HAMILTON MARTIN 1117
A twig canker of apple caused by Nectria cinnabarina. H. E. THOMAS and A. B. BURRELL 1125
Stem-rust-resistant segregates from wheat crosses between two susceptible parents. GEORGE STEWART 1129
The effect of land plaster applied as a dust on seed corn. E. N. BRESSMAN 1131
Report of the thirteenth annual meeting of the Pacific Division of the American Phytopathological Society 1135

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PHYTOPATHOLOGY

VOLUME XIX NUMBER 1

JANUARY, 1929

THE RELATION OF WEATHER TO THE DEVELOPMENT OF STEM RUST IN THE MISSISSIPPI VALLEY[1]

EDMUND B. LAMBERT[2]

INTRODUCTION

It is well known that destructive epidemics of stem rust, *Puccinia graminis* Pers., occur in the spring wheat area during certain seasons, while other seasons are comparatively free from rust. Obviously it is important to know the reasons for this fluctuation. As the development of epidemics was studied year after year, it has become more and more evident that many interdependent factors are involved. In the Northern States all phases of the life cycle of the rust organism must be considered. The development of rust throughout the entire Mississippi Valley also seems to have a bearing on the problem. Seasonal weather conditions appear to be an important factor, but until recently our information on this subject has been based on more or less isolated observations.

Controlled experiments (15, 19, 20, 41, 44, 45, 46, 47, and 58) have indicated that temperature and moisture conditions profoundly influence the germination of teliospores and sporidia, the germination and longevity of urediniospores, the germination of aeciospores, and the rate of development of aecial and uredinial infection. Field observations have been made, but there is no unanimity of opinion. Certain workers (6 and 24) believe low temperatures favor the development of epidemics. Some investigators (14, 33, 58 and 64) have presented evidence that warm growing seasons are correlated with heavy rust development; others (2 and 67) are inclined to believe that rainfall is the major factor; still others (11, 12, and 54) suggest that high humidity and dew are more important than rainfall. No

[1] The data presented in this paper were obtained in cooperative investigations by the Office of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture, and the Department of Agriculture of the University of Minnesota; and submitted to the graduate faculty of the University of Minnesota in partial fulfillment of the requirements for the degree of Doctor of Philosophy, granted June 13, 1927.

[2] The writer gratefully acknowledges his indebtedness to Dr. E. C. Stakman for access to unpublished papers on the epidemiology of stem rust, and for encouragement and helpful criticism during the progress of the investigation.

one, however, has attempted to present a perspective of the relation of weather to all of the different phases of the development of epidemics as they occur in the Mississippi Valley.

STATEMENT OF THE PROBLEM

A brief sketch of the way stem rust develops in the Mississippi Valley seems necessary as a basis for a discussion of the rôle played by the weather. Apparently no two epidemics develop in exactly the same manner. But, although they vary considerably from year to year, the general sequence of events is usually the same. The field studies of Stakman and others[3] indicate that the cycle of the rust is different in the Southern States from that in the Central and Northern States. This is represented diagrammatically in figure 1.

In southern Texas the uredinial stage of the rust increases slowly from October to January. It then decreases in amount in January and February, reaching low ebb in March. It steadily increases from April and May until harvest. In northern Texas and Oklahoma the cycle is approximately the same except that the rust as a rule probably does not persist through March and April, and the development in the spring usually does not begin until May.

In northern Kansas and Nebraska, there is no conclusive evidence of the persistence of the uredinial stage through the winter and spring months. Barberries become infected late in April and early in May, and spread rust to grain and grasses in May. Otherwise the cycle is similar to that in northern Texas and Oklahoma.

The germination of teliospores and the infection of barberries are the first indications of an approaching epidemic in the spring wheat area. The teliospores begin to germinate early in April, and pycnia usually appear on barberries in late April and early May. Usually stem rust is spreading from barberries to grasses and grain during the last two weeks in May. Toward the middle of June primary infection begins to appear in the wheat fields throughout the southern part of the area, regardless of their proximity to barberries. In most years there is a general sprinkling of primary infection on susceptible grains as far north as the Canadian border by the first of July. From then until harvest successive generations of rust develop at intervals of from five to ten days. Most of the damage caused by

[3] These studies have been made by the Office of Cereal Crops and Diseases, U. S. Department of Agriculture, under the direction of Dr. E. C. Stakman, each year for the past eight years. At present they are in the form of unpublished progress reports. The writer has had access to these reports because he assisted in the work for the past five years. Much of the material presented in this paper was obtained during that time.

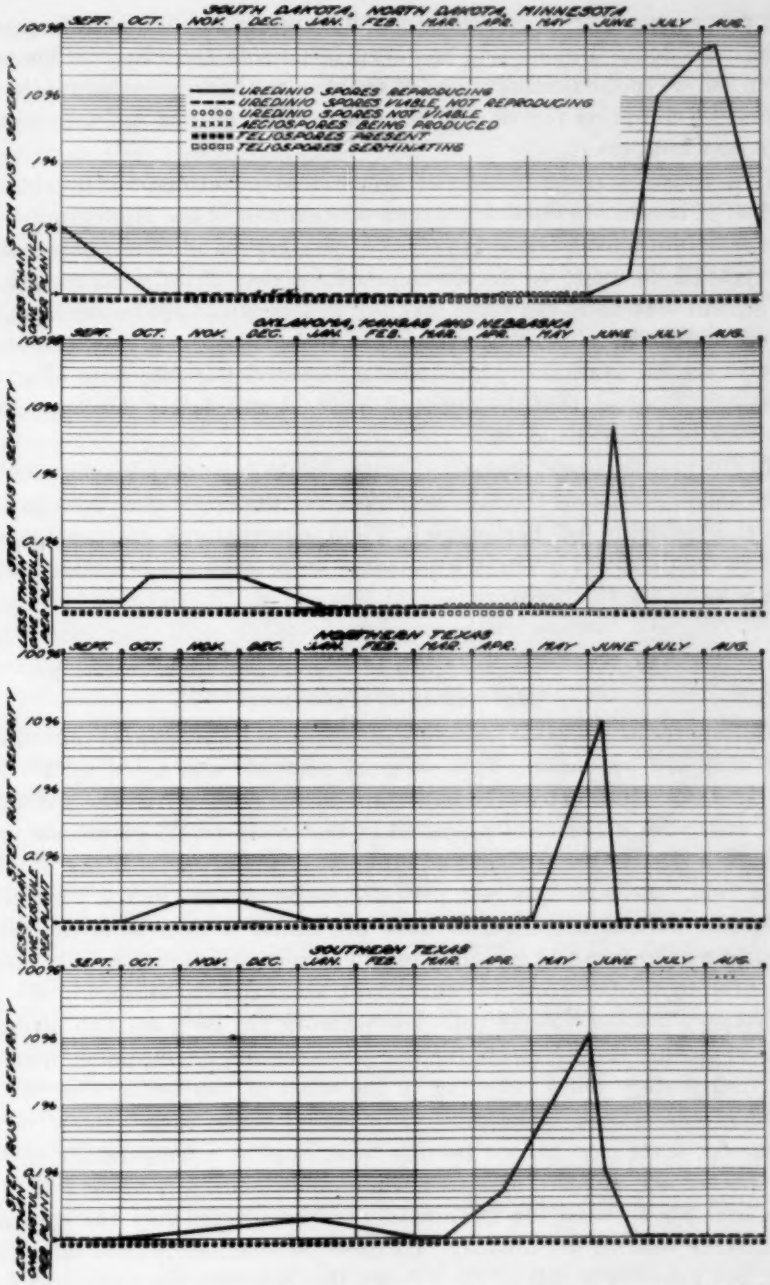

FIG. 1. Diagram of the approximate development of the different phases of the life cycle of stem rust in the average year in the western Mississippi Valley.

stem rust occurs shortly before harvest, during the period when the grain is filling. In South Dakota and southern Minnesota the wheat is harvested late in July. In the northern part of the area the harvest continues through August. Teliospores remain viable until the next season, but the uredinial stage does not persist.

It is apparent from this brief sketch that an attempt to analyze the relation of weather to the development of stem rust in the Mississippi Valley must take into consideration the effect of weather on all of the phases in the life cycle of the rust; on the development of rust in different regions and in different seasons of the year; and on the severity of epidemics from year to year. Finally, it must be recognized that the effect of weather on one phase of the life cycle may profoundly influence the development of another phase and, likewise, that the regional, seasonal and yearly developments of rust may be interdependent.

In the present work, controlled experiments have been largely confined to the determination of the factors influencing the maturation of teliospores and the infection of barberries. Field observations and comparative weather data also are given in an attempt to present a perspective and lay a foundation for further work.

MATURITY AND GERMINATION OF TELIOSPORES AND SPORIDIA

Maturation of Teliospores

Teliospores of *Puccinia graminis* rarely, if ever, germinate immediately after they are produced. This seasonal response was noted by De Bary (16) in 1865. It is extremely important in the economy of the pathogene, since, otherwise, teliospores produced in the North would germinate in the fall rather than in the spring, and eliminate themselves from the life cycle of the rust. Because this rest period is so important in the function of teliospores, several investigators have attempted to determine the factors affecting maturation and germination. The rest period conceivably may be influenced by temperature, moisture, light, and chemical stimuli.

Temperature.—Although considerable work has been done to determine the temperature requirements for the germination of teliospores, there are only fragmentary notes referring to the effect of temperature on the rest period of the spores. McAlpine (35) placed badly rusted straw in cold storage for three months, one portion being kept at a temperature of 4° C. and another at −18° C. A third portion of the same straw was left in the open, and when tested for germination in the spring, only the spores exposed to the weather germinated. He drew no conclusions from this experiment, but apparently was of the opinion that temperature was not a major factor. Klebahn (32), after testing the germination of teliospores of *P.*

graminis, stored indoors and outdoors under various conditions, concluded that winter cold was not necessary but seemed to have an accelerating effect on germination. Thiel and Weiss (63) were unable to shorten the rest period of teliospores by exposure to −10° C. and to alternate freezing and thawing in December.

During the winters 1924–28 the writer has subjected teliospores to different constant temperatures and relative humidities to determine their effect on the maturation period. In one experiment, teliospore material of *P. graminis secalis, P. graminis tritici,* and *P. graminis avenae* was collected in September, 1923, and stored at three different temperatures, 10°, 22°, and 35° C., in constant humidities. Germination tests were made with this material in September, December, and April, by floating the spores on the water at 18° C. Only the *secalis* strain germinated. This material was on *Agropyron repens.* As indicated in table 1, the spores germinated abundantly when stored at 10° and 22° C., but none of the spores kept at 35° C. seemed to be viable. The experiment was repeated with spores of *P. graminis tritici* in the winter of 1924–1925. In this experiment an additional series was kept at 0° C., making four constant temperatures. The results of this test, which are also included in table 1, were essentially in agreement with those obtained with the *secalis* strain. The percentage of germination was low in all lots except that stored at 35° C., in which none of the spores germinated. In both winters, spores from the same collections were stored outdoors as checks on the germination of those kept at constant temperatures. These spores germinated at the same time and approximately as well as those stored indoors.

To test the effect of alternate freezing and thawing on the period of dormancy, dry and wet spores of *Puccinia graminis secalis* were alternately frozen and thawed at approximately 10-day intervals throughout the winter of 1923. None of these spores germinated until spring, nor did any of the wet spores germinate even at that time. In this connection it may be noted that the writer has on several occasions confirmed the observations of Melhus *et al* (41) that spores lying on the ground germinate very sparingly, if at all, in the spring. In April the dry spores which had been alternately frozen and thawed germinated as well as, but no better than, two other lots of dry spores which had been kept as checks, one indoors and the other outdoors.

These results indicate that a high temperature, 35° C., for long periods is injurious to teliospores. Otherwise, temperature does not seem to be a major factor in determining their maturation.

Moisture.—The effect of drying, and especially alternate wetting (soaking) and drying, on the maturation of teliospores of various rusts has been

TABLE 1.—*The effect of different constant temperatures and humidities on the rest period of teliospores of Puccinia graminis secalis and Puccinia graminis tritici as indicated by germination tests*

Stored in the dark at		Average germination at 18° C. in duplicate trials[a]						
		Puccinia graminis secalis stored in Sept., 1923, and germinated				*Puccinia graminis tritici* stored in Sept., 1924, and germinated		
Temperature, degrees C.	Relative humidity, per cent	Sept. 29, 1923	Dec. 29, 1923	Apr. 18, 1924	Apr. 24, 1924	Sept. 18, 1924	Apr. 2, 1925	Apr. 24, 1925
0–2	0	–	–	–	–	0	tr	+
	20	–	–	–	–	0	0	+
	40	–	–	–	–	0	+	0
	60	–	–	–	–	0	+	tr
	80	–	–	–	–	0	0	tr
10–15	0	0	0	+	+	0	0	tr
	20	0	0	+	+	0	tr	tr
	40	0	0	+	+	0	0	+
	60	0	0	+	+	0	0	+
	80	0	0	+	++	0	0	tr
22	0	0	0	+	0	0	0	tr
	20	0	0	0	+	0	tr	0
	40	0	0	+	++	0	+	0
	60	0	0	+	+	0	0	0
	80	0	0	0	tr	0	0	0
35	0	0	0	0	0	0	0	0
	20	0	0	0	0	0	0	0
	40	0	0	0	0	0	0	0
	60	0	0	0	0	0	0	0
	80	0	0	0	0	0	0	0

[a] 0 – no germination.
tr – few spores germinating.
+ – at least one clump of spores germinating abundantly.
++ – more than 10 per cent germination.

noted repeatedly (37). Klebahn (32) made controlled experiments with *P. graminis*. In the winter of 1911, he stored a collection of spores in three different ways: indoors in a dry room; in the open exposed to cold and dampness, but not to rain; and indoors alternately wet and dried at three-day intervals.

Those spores which were wet and dried at frequent intervals germinated in the spring, while the others did not. In 1912 he repeated the experiments, using running water to wet the spores. In this experiment the spores which were alternately wet and dried germinated well in January, but less than 1 per cent germinated when they were kept in a warm dry room. He concluded that the most important factor for germination was saturation and drying. The writer was unable to confirm these results with teliospores collected in the spring wheat area in September, 1924. A part of this material, on *Agropyron repens*, was kept at 5° C. and alternately wet and dried at approximately weekly intervals throughout the winter. Repeated germination tests with both the check and treated material failed until March and April, when clumps of spores germinated in both lots. There was no measurable difference between the germination in the check and the treated material. The experiment was repeated in 1925, but all the material used failed to germinate in the spring.

The experiments already described to determine the effect of temperature were also adapted to determine the effect of constant humidities on the rest period of teliospores. At each of the four temperatures, the straws bearing the spores were placed in sealed Mason jars which contained sulfuric acid, or saturated salt solutions to fix the humidity. In 1923 different concentrations of sulfuric acid were used, as suggested by Wilson (66). In 1924 saturated salt solutions were used to control the humidity, according to the method described by Headlee (26). Five jars were used at each temperature and the relative humidity in them was adjusted to approximately 0, 20, 40, 60, and 80 per cent. The results are given in table 1. It is apparent that differences in relative humidity had no appreciable effect on the rest period or viability of teliospores.

In 1923 a similar series of five sealed jars was set outdoors. The material in these jars reacted quite similarly to that in the jars kept indoors. Small percentages of spores germinated in the spring, but there were no great differences between the amount of germination of the material kept at different humidities. The response obtained in these experiments was different from that obtained by Klebahn. This may have been due to the material used, or to the conditions of the experiment. However, it is clear that alternate wetting and drying is not always necessary for the maturation of spores. Under some circumstances it may shorten the period of

dormancy, but the evidence of this does not seem clear cut enough to consider alternate wetting and drying as a limiting factor in the maturation of teliospores.

Light.—In the experiments described above, in which the spore material was kept at constant temperatures and humidities, the spores were stored in the dark. The fact that these spores germinated proves that light is not necessary for maturation, but there was no check material kept in the light to compare with that stored in the dark. Therefore, two additional experiments were made to determine the effect of this factor. In one case, teliospores were exposed constantly to artificial light for two months early in the winter. This treatment failed to shorten the rest period. The second experiment was begun in September, 1923. Straw of *Agropyron repens* bearing fresh teliospores was placed in four glass jars; two of these were painted black, and two were left unpainted. One of the blackened and one of the unpainted jars were sealed; the other two were left open, but inverted over a wire screen in such a way as to allow air to enter but to exclude direct sunlight from the blackened jar. Germination tests were made in April of the following spring. Clumps of spores taken from the material in all of the jars germinated vigorously. There was no measurable difference between the percentages of germinating spores when kept in the dark and when kept in the light.

Chemical stimuli.—In 1920, Thiel and Weiss (63) offered two hypotheses to account for the rest period: after-ripening of the spore contents, and relative impermeability of the spore wall to water. They attempted to shorten the rest period by applying methods which had been effective in shortening the rest period of seeds. Keeping the spores at constant low temperatures and subsequent freezing and thawing failed to stimulate them. Lipoid solvents and various acids also were used in an attempt to modify the permeability of the spore wall, or to affect the enzymic changes occurring within the spore protoplasm and to increase its hydration capacity. All of the lipoid solvents and acids which were tested were ineffective in stimulating germination, except citric acid. Teliospores which were exposed to chloroform vapor for one minute, followed by a fifteen-minute immersion in 1 per cent citric acid, germinated in December, when check material would not germinate. The treatment was repeated twice in December, twice in January and once in February with consistent results. They were inclined to believe that citric acid acted as a specific stimulant, because other acids did not produce a similar effect.

The writer has attempted on several occasions to use this method of stimulating teliospore germination, but it has never been successful. Several modifications of the method also have been tried without success. In

addition, numerous other chemicals were used in attempts to shorten the rest period. The following are a few of the chemicals tested: straw extracts, and extracts of decayed and living plant tissue in various concentrations; benzaldehyde, salicylaldehyde, citraldehyde, several alcohols; the sixteen essential oils used by Noble (43) to stimulate the spores of *Urocystis tritici;* ethylene gas; and ethylene chlorohydrin, which Denny (17) found to be an effective stimulant for breaking the rest period of potatoes.

Several nitrate salts and a series of salt solutions (13) ranging in pH value from 5.2 to 8.0 also were tried in several concentrations. Germination tests were made also with spores in water containing growing roots and on the surface of distilled water under bell jars beside growing plants. None of the methods or substances tried appeared to influence markedly the rest period. There was some evidence of increased germination when certain of the chemicals were applied to matured teliospores. This will be discussed later in connection with the factors affecting the germination of mature spores.

It is quite possible that a chemical method of shortening the rest period of teliospores will be found in the near future, but the writer is inclined to believe that chemical stimuli do not play an important part in the germination of teliospores in nature. There is a possibility that material such as the products of decaying straw, enzymes produced by saprophytes on the straw, or volatile oils from the spring flora may influence the rest period in nature. But teliospores usually germinate on straw and not in the soil or on the barberry. Therefore the presence of host tissues would not be expected to stimulate them in the same manner as it does the spores of *Botrytis cinerea* Pers. (9) or *Urocystis tritici* Koern. (43), for example. Moreover, teliospores which matured under controlled conditions germinated when these factors were not operating, and immature spores did not germinate when many chemical stimuli were present. Furthermore, in the writer's cultures a few spores have matured in December and they often mature in February, before many external stimuli have had a chance to operate.

Time.—Reference already has been made to the fact that teliospores of *Puccinia graminis* which are formed in the fall usually do not germinate until spring.

In the past five years at St. Paul, Minnesota, teliospores have begun to respond to favorable conditions for germination in February. When tested in distilled water at 18° C., spores collected in the vicinity of University Farm, St. Paul, Minn., germinated on the following dates:

1923—February 26[4]—on *Agropyron repens*
1924—January 18 —on *Poa pratensis*

[4] Tests in 1923 were made by D. L. Bailey, formerly agent in the Office of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture.

1925—January 21 —on *Triticum vulgare*
1926—March 3 —on *Agropyron repens*
1927—February 25 —on *Agropyron repens*

On these dates only a few spores in several hundred germinated. Maximum germination did not occur until April. This is approximately the season recorded by other workers. Dietel (19) found that teliospores of *P. graminis* began to germinate in March in central Germany. In Australia, according to McAlpine (35), "It is only after a considerable rest that they will germinate and they start on warm days about the end of September, which is the beginning of our spring. This may continue to the warmer days of October, almost or entirely ceasing in a cold spell, and even until November germination continues if conditions are favorable; but, although numerous trials have been made, no germination has occurred outside of these months." Eriksson (20) showed that in Stockholm, Sweden, these spores germinated under natural conditions in April and May. At Madison, Wisconsin, and Ames, Iowa, Melhus *et al* (41) also found that, under natural conditions, teliospores of stem rust become viable in April.

This apparent dormancy of teliospores throughout the winter months suggests that time is necessary in order to enable certain changes to take place in the spore, possibly changes in the physical state of the protoplasm which transform it from a gel to a hydrosol as suggested by Price (50). The mere fact that spores formed in the fall failed to germinate until spring is not conclusive evidence that time is the most important factor, unless it can be shown that no external stimulus has acted in the intervening period.

However, two kinds of evidence indicate that time is an important factor. In the first place, it has been shown that teliospores do not readily respond to external stimuli such as temperature, moisture, light, and chemicals. In fact, most of the efforts which have been made to induce spores to germinate before February have failed. Secondly, teliospores kept under controlled conditions would not germinate in the winter, but germinated readily in the spring. This was demonstrated in two separate seasons. In these experiments, unknown external stimuli could hardly account for the difference in the spores in the winter and spring, because the material was kept at constant temperature and moisture in the absence of light and the spores germinated in distilled water. All of the evidence at hand points strongly toward the conclusion that teliospores have a true rest period which carries them through the fall and early winter months during which environmental conditions apparently have little effect on the spores.

Germination of Mature Teliospores

After teliospores have matured, their germination and the production of sporidia may be influenced by humidity and temperature. Light and the reaction of the medium do not seem to be important.

Moisture.—Melhus *et al* (41) compared the germination of teliospores in water and in atmospheres of different relative humidities. They agree with Blackman, Magnus, and Kunkel that only abnormal germ tubes, and seldom sporidia, are formed under water. Abundant germination and sporidial formation occurred in a saturated atmosphere, but only a few sporidia were produced at 95 per cent relative humidity, and none were formed in less humid atmospheres. These experiments indicate that in nature germination and liberation of sporidia must take place during rains.

Temperature.—According to Dietel (19), the cardinal temperatures for the production of sporidia are 9.5° C., 22° C., and 23° C. Melhus *et al* (41) essentially confirmed these results, but in their experiments the germination was best at 20° C. and growth and the production of sporidia were barely noticeable at 5° C. In the writer's experiments the spores germinated well at 12–18° C. but they germinated most consistently at 18° C.

Light.—To determine the relation of light to germination, spores of *P. graminis secalis* and *P. graminis tritici* were placed in full sunlight, diffused light, and darkness, at approximately 18° C. The tests were made with the spores floating on distilled water in sealed syracuse dishes. Some difficulty was experienced in regulating the temperature, but in cases where the water in the different dishes was at approximately the same temperatures, there were no consistent differences between the percentages of germinating spores when exposed to diffuse sunlight and when in the dark.

Hydrogen-ion concentration.—A limited number of experiments were made with the standard buffer solutions of Clark (13) to determine the range of hydrogen-ion concentration in which teliospores will germinate. The solutions of phosphoric and thallic acid were diluted by adding one part of the standard solution to five parts of distilled water. The spores were sown on the surface of the liquid and tested in duplicate series at 18° C. The H-ion concentrations were checked first with a potentiometer and later by colorimetric tests. In the first germination tests made January 19 and repeated January 26, 1922, the spores responded in only a narrow range of H-ion concentration, pH 5.8–6.2. In April, spores from this same collection germinated in a wider range, pH 5.2–7.8. Another set of spores, collected in the fall of 1926 and tested in February, 1927, germinated in a pH range from 5.0 to 7.0.

The response of the spores in the first collection to a narrow range of H-ion concentration in January and a wider range in April is interesting.

It suggests that the maturity of the spores either may have been affected by, or caused by, changes in the reaction of the spore contents, resulting from the accumulation of products of oxidation. It is evident that some collections of teliospores will germinate in a fairly wide range of H-ion concentration, probably wide enough so that they would not be affected by fluctuations which might occur in the reaction of the teliospore sorus in nature.

Time required.—Different collections of teliospores differ considerably with regard to the time required for germination. Some of this difference may represent seasonal response. Deitel (19) was probably the first to suggest this. He found that teliospores of *P. graminis* from *Agropyron repens,* collected in March, required 30 hours to germinate; later, germination took place in 2¾ hours; in June 4½ hours were required; and in July only a few spores germinated in 30 hours; in August no spores germinated, even within 36 hours. The writer has noted a similar seasonal response in the time required for germination, and, in addition, a tendency for spores from different sori on the same straw to require different lengths of time for germination. In 1924, spores from *Poa pratensis, Agropyron repens,* and *Agrostis alba,* collected in March, required 3 days to germinate, while in April spores from the same material germinated abundantly in 12 hours. Similar results were obtained again in 1925, with spores from *A. repens.* Collections of spore material have been tested which required 5 days to germinate. The minimum time for the germination of teliospores and the production of sporidia was approximately 6 hours. The average time was about 12 hours.

Most of the tests were made by scraping the spores off of the straw on to the surface of distilled water. In doing so, clumps of spores representing different sori from the same straw were often deposited intact on the water. In some dishes the time required for these individual clumps of spores to germinate varied from 12 to 24 hours. Eriksson (20, 21) believes that "Only the crop of spores maturing during the late autumn is able to germinate the following spring." This suggests the possibility that the difference in the response of spores in separate sori may be due in part to conditions at the time of the formation of the teliospores.

Both the seasonal response and the differences in the response of different material and of different sori may affect the period in which teliospores germinate in the spring. As a result, all of the teliospores in a given locality do not germinate in the first heavy rainfall. They germinate and produce sporidia during several rainy periods. This undoubtedly aids in synchronizing the time when teliospores germinate in the spring with the time when barberry leaves unfold.

Longevity of Mature Teliospores

Once teliospores have been shown to be viable in the spring, the following questions naturally arise: how long will these spores remain viable and what affects their longevity? It has been observed repeatedly that under natural conditions they usually are comparatively short-lived. Eriksson (20) noted that in the vicinity of Stockholm, Sweden, teliospores of *P. graminis* lost their viability in June. McAlpine (35) mentions the middle of October as the height of the season for germination in Australia, and states that, under favorable conditions, spores germinate until November, but germination never has been observed later.

Melhus *et al* (41) obtained plentiful germination in April and May, but spores left out of doors would not germinate in June or July. They observed that the cells of most of the spores became empty following heavy rains. The writer found that similar conditions existed at St. Paul, Minn., in 1923 and 1924, and was also able to distinguish clearly between germinated and non-germinated spores by the appearance of the spore contents.

Eriksson, Melhus and his co-workers, and Waterhouse have gone a step further and attempted to prolong the period of viability of the spores by drying and cooling them. Eriksson (20) was able to keep viable teliospores on *Avena sativa* and *Triticum vulgare* from May until September, simply by bringing them into a dry laboratory. Melhus *et al* (41) were able to keep them a few weeks longer by storing them in a cool dry place. Waterhouse (65) divided into two lots straw which contained viable teliospores in April, keeping one portion at ordinary laboratory temperature and the other in cold storage at a temperature a little above the freezing point. In the former, the percentage of germination began to decrease in June, while in the latter the spores germinated abundantly and were capable of infecting barberries until the end of July.

In April, 1925, the writer and R. U. Cotter[5] stored teliospores on *Poa pratensis* and *Agropyron repens* at different temperatures and relative humidities. Having a need for viable telial material to inoculate barberries in the varietal tests throughout the winter, a burlap sack was filled with the telial material on *Agropyron repens* and placed in cold storage at approximately 2° C.

In addition, bits of infected straw were sealed in 20 Mason jars which were kept at four different temperatures and adjusted to five different humidities. The results of germination tests with the material in these jars are given in table 2. It will be noted that material kept dry and at the

[5] Agent in the Office of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture.

TABLE 2.—*The effect of temperature and moisture on the longevity of mature teliospores of Puccinia graminis secalis and Puccinia graminis poae, which germinated normally on April 25, 1925*

Stored April 25, 1925		Germination[a] tests, 1925									
		July 7				Nov. 11				Dec. 28			
Temperature, degrees C.	Relative humidity, per cent	*P. graminis poae*		*P. graminis secalis*		*P. graminis poae*		*P. graminis secalis*		*P. graminis poae*		*P. graminis secalis*	
		Trial		Trial		Trial		Trial		Trial		Trial	
		A.	B.	A.	B.	A.	B.	A.	B.	A.	B.	A.	B.
0–2	0	++	++	++	+	++	++	++	+	+	+	tr	tr
	20	++	++	++	++	++	++	tr	tr	+	tr	tr	tr
	40	++	++	tr	+	++	++	0	0	tr	0	tr	tr
	60	++	++	++	++	++	++	–[b]	–	tr	0	–	–
	80	++	++	tr	tr	tr	tr	++	tr	tr	tr	tr	tr
10–15	0	++	++	0	tr	0	0	+	+	0	0	0	0
	20	++	++	0	0	0	0	tr	0	0	0	0	0
	40	+	++	tr	tr	0	0	0	0	0	0	0	0
	60	tr	tr	0	0	0	0	0	0	0	0	0	0
	80	tr	tr	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0
	20	tr	0	0	0	0	0	0	0	0	0	0	0
	40	0	0	0	0	0	0	0	0	0	0	0	0
	60	0	0	0	0	0	0	0	0	0	0	0	0
	80	0	0	0	0	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0	0	0	0	0	0
	20	0	0	0	0	0	0	0	0	0	0	0	0
	40	0	0	0	0	0	0	0	0	0	0	0	0
	60	0	0	0	0	0	0	0	0	0	0	0	0
	80	0	0	0	0	0	0	0	0	0	0	0	0

[a] 0 = no germination.
tr = few spores germinating.
+ = at least one clump of spores germinating abundantly.
++ = more than 10 per cent germination.

[b] Spores wet with acid.

lowest temperatures remained viable for the longest time. The tests with this material were not continued after December because most of the straw had, by that time, been used for the germination tests. However, Cotter continued his inoculations with the spores which had been kept in cold storage and was able to obtain infection until spring, when the old material was discarded for spores formed in the fall of 1926. This procedure has now become routine. Another set of spores which was placed in cold storage in the spring of 1926 was still being used to infect barberries in March, 1927.

It seems probable from these observations and experiments that most of the teliospores which mature in March or April will germinate in the spring; only a few will germinate in the summer because of high temperatures, but conditions may be favorable for germination again in the fall, and the remaining viable spores may germinate at that time.

Production, Liberation, Dissemination, and Germination of Sporidia

The conditions necessary for the production of sporidia appear to be essentially the same as those necessary for the germination of teliospores, except that teliospores will germinate under water, but sporidia are never produced under water. If a promycelium is produced under water, it will not bear sporidia unless the sterigmata grow out above the surface of the water. Promycelia from spores lying on the surface of the water usually are several times longer than those from spores on damp straw.

As pointed out by Buller (10), the sporidia usually are formed on the upper surface of the promycelium, where they sometimes germinate without leaving the sterigmata. A promycelium growing from a spore produced on a damp piece of straw almost always is shorter than one growing in water and is curved at right angles to the spore so that the sporidia are borne on sterigmata on the convex surface away from the straw. This production of the sporidia on the surface of the promycelium away from the spores is regarded by Buller (10) and Melhus *et al* (41) as an adaptation to facilitate the liberation of the spores.

Buller (10), in 1917, was the first to report that the sporidia of *P. graminis* normally are abjected forcibly from the sterigmata. He carefully observed the rate of the development of the spore at the end of the sterigmata and noted that the average time required for development from a tiny rudiment to a full grown spore was 20 minutes. It was estimated that a full-sized spore required about an hour of ripening before it was shot away. During this period of growth and ripening of the spore, the relative humidity of the air surrounding the spore must be comparatively high or the promycelium will collapse before the spore is fully formed and

matured. These observations clearly demonstrate that sporidia are liberated by a mechanism which assists in wind dissemination. Once the teliospores have matured, a moderately warm (10°–25° C.) 10-hour rain should be sufficient for their germination and the liberation of sporidia.

The mechanism for spore liberation makes it seem probable that sporidia of *P. graminis,* as well as those of other rusts (55), are disseminated by the wind. Aside from this, very little is known regarding the way these spores are distributed. Field observations indicate that teliospores usually can be found within a quarter of a mile of infected barberries. Bushes in city plantings flanked by clipped lawns seldom have more than a half-dozen cluster cups on them.

The writer has examined hundreds of barberry plantings and has found teliospores within a hundred yards of the bushes in all cases in which the barberries were infected heavily enough to be a factor in the development of a destructive epidemic. Owing to their boat-like shape, sporidia have an enormous surface as compared with their mass. Therefore they probably are carried long distances by the wind, and there probably is a general dissemination of sporidia. But this general dissemination is apparently too sparing to cause a heavy infection on barberries.

The optimum temperature for the germination of sporidia (41) is between 15° and 20° C. They oftentimes germinate at 18° and 20° C. while still attached to the sterigmata; they will also germinate on solid media, apparently not requiring actual contact with drops of water.

INFECTION OF BARBERRIES AND THE LIBERATION, DISSEMINATION, AND GERMINATION OF AECIOSPORES

The importance of barberries as a source of inoculum depends on the physiologic form of stem rust present, the severity of infection, and the number of spores produced. These in turn depend on a number of factors: the species, abundance, and proximity of susceptible grasses and cereal hosts, the severity and time of infection in the previous year, and weather conditions. Emphasis will be placed here on the relation of weather conditions to the geographic distribution of barberry rust and to the seasonal fluctuation in severity of infection.

Geographic Distribution of Barberry Rust

The maturation and germination of teliospores in spring are important factors determining the distribution and severity of barberry rust. Field observations[6] over a period of eight years indicate that, in the Mississippi Valley, barberry rust is most abundant in the Northern States, sparing in

[6] Unpublished papers of Stakman *et al.*

Missouri and Kansas, and practically absent in Texas and Oklahoma. This distribution appears to be due largely to the viability of teliospores.

Stakman, Kirby, and Thiel (57) have shown this by field experiments. They inoculated barberries in the south with three types of inoculum: teliospores which were formed and matured in the south, spores which were formed in the south and kept over summer and winter in the north, and spores developed in the north. It was found that barberries would not become infected in the Southern States when inoculated with teliospores matured in the south. On the other hand, when they were inoculated with spores kept through the summer and fall in the north, excellent infection was obtained whether the spores were formed in the north or the south. They state, "Numerous germination tests were made and the results of the germination tests correlated with the facts observed regarding infection. Evidently, therefore, the reason why barberries do not become infected in the south is not because conditions are unfavorable for infection, but because practically no teliospores are viable in the spring."

The reason for this lack of viability has not been definitely ascertained. There are two possibilities. The teliospores either germinate during the winter or they are killed by the high temperatures which prevail during the hot summers in the south. Controlled experiments, which have already been discussed, tend to substantiate the latter hypothesis. In this connection it is well to recall that in Texas, Oklahoma, southern Kansas, and southern Missouri teliospores are formed in May and June, and therefore must endure the hot months of July, August, and September. In the spring wheat area, they are formed mostly in July and August, and it is not necessary for them to withstand so long a period of hot weather.

Severity of Barberry Infection

Temperature.—Assuming the presence of viable teliospores near the barberry, the two most important factors determining the abundance of infection seem to be temperature and moisture. Light plays only a minor rôle. Temperature appears to be a factor in determining the season of the year when barberries become rusted and the date of primary infection, while rainfall often determines the amount of infection in a given locality.

As mentioned previously, the temperature range for the germination of teliospores and the production of sporidia was determined by earlier workers to be between 10° and 25° C., with an optimum at 20° C. It was also determined that the germination of sporidia occurred principally between 15° and 20° C. To supplement these observations, Melander[7] (40) and the

[7] These experiments were made jointly by the writer and L. W. Melander, who is Associate Pathologist in the Office of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture, in charge of barberry eradication in Minnesota.

TABLE 3.—*The effect of temperature during incubation upon the infection of Berberis vulgaris with Puccinia graminis secalis*

	Temperature, degrees C.	No. plants used	No. leaves		No. petioles infected	No. shoots		Degree of infection
			inoculated	infected		inoculated	infected	
First trial June 1, 1923	17–18	8	163	105	42	22	20	Heavy
	22–23	8	154	52	10	7	5	Light
	26–28	8	130	0	1	12	0	One small pustule
	31–33	8	142	1	0	13	0	One small pustule
Second trial June 20, 1923	17–18	4	76	25	3	0	0	Heavy
	22–23	4	80	46	6	0	0	Light
	26–28	4	95	0	0	0	0	———
	31–33	4	106	0	0	0	0	———

writer attempted to determine the effect of temperature, under controlled conditions, on the extent and severity of barberry infection. Straws bearing viable teliospores were tied to barberries, which were then sprayed with water and immediately placed at the bottom of sealed constant temperature tanks. To facilitate infection, the air in these tanks was kept at approximately 100 per cent relative humidity for 72 hours. The degree of infection was noted 10 days after inoculation. By that time aecia already had developed on many of the leaves. As indicated in table 3, the greatest amount of infection occurred at 17–18° C. It was slight at 22–23° C., and there was little or none at 26° C. This experiment indicates that the combined process of teliospore germination, sporidia formation, liberation, and germination, the infection of barberry leaves, and the development of aecial cups are retarded or prevented by temperatures higher than 22° C. This comparatively low optimum for infection is probably one of the reasons for the scarcity of barberry infection in the summer.

In spite of the fact that fresh aecia usually are scarce in midsummer, in certain seasons barberries may become quite heavily rusted in September. This was especially noticeable in Minnesota in the fall of 1921. This fall infection may have been due to germination of newly formed teliospores, but when it is remembered that the summer of 1921 was exceptionally dry, and that dry teliospores may remain viable several months after they mature, another explanation for the fall infection suggests itself. The teliospores may have remained viable throughout the summer, but the rains were not cool enough for germination and infection until September. Thus the low optimum temperature for infection apparently is expressed in the field by abundant spring infection, scarcity of barberry rust in the summer, and an occasional renewal of infection in the fall. The comparative abundance of barberry rust early in the spring is probably also due partly to the fact that only young barberry leaves are highly susceptible.

Because of its earliness, this primary infection is usually the most important on the furnishing of inoculum for the development of widespread epidemics. The dates of first infection on barberries have been recorded accurately in Minnesota for 1921–26.[8] The comparative severity of state-wide infection also has been noted. These observations are summarized in table 4. The outstanding features of these six years' observations are the early infection in 1921, the late infection in 1924, and the comparatively light infection in 1926.

An attempt has been made to determine if unusual weather conditions were associated with peculiarities in the infection of barberries in these

[8] Unpublished papers of Stakman *et al.*

TABLE 4.—*The dates of first appearance of pycnia and the comparative state-wide severity of rust on barberries in Minnesota, 1921 to 1926 inclusive*

Year	Date of first infection	Stage of development	County	Observer	Comparative state-wide severity of rust
1921	April 25	Pycnia	Jackson	L. W. Melander	Heavy
1922	May 4	do	Rice	do	do
1923	4	do	do	J. J. Christensen	Moderate
1924	12	do	Goodhue	L. W. Melander	do
1925	1	do	Olmstead	do	do
1926	1	do	do	do	Light to moderate

years. The departures from the mean monthly temperatures in March, April and May of these years are given in table 5.

These departures suggest that two factors operated to produce the early infection in 1921: first, the month of April was much warmer than usual; and second, rains occurred from the 6th to the 9th which were heavy enough to delay farm work. Since April, 1925, was also warmer than normal, infection might be expected in that year earlier than May first, but during April, 1925, there was a short cold spell near the end of the month when temperatures in general fell considerably below the freezing point. This probably explains the delayed infection in that year.

A similar cold spell which occurred early in May, 1924, seems to be correlated with the exceptionally late infection in that year. "The month was abnormally cold. In all the 34 years' record there was but one made, that of 1907, which was colder. . . . A warm period of two or three days' duration began on the 15th and throughout the remainder of the month it was consistently cold, especially during the first week when freezing was

TABLE 5.—*The departure from the normal temperature[a] for March, April, and May, in Minnesota, 1921 to 1926 inclusive*

Year	March	April	May
1921	+2.7	+3.5	+2.1
1922	+2.1	−0.3	+5.2
1923	−8.4	−2.6	+1.0
1924	+1.2	−1.8	−7.3
1925	+4.3	+5.7	−2.2
1926	−2.8	−1.3	+4.4

[a] The 36-year averages given in Climatological Data for 1926 were used as normal; they were March 26.3°, April 43.3°, and May 55.0° F.

the rule.''[9] There appears to be no correlation between the temperature in March and the earliness of barberry infection.

Rainfall.—The light infection which occurred in Minnesota in 1926 seems to be correlated with the exceptional drought during April, when there were only three days with measurable precipitation in the month. The last two weeks in April is usually the period when barberry leaves begin to develop in Minnesota. As shown in figure 2, there was a general

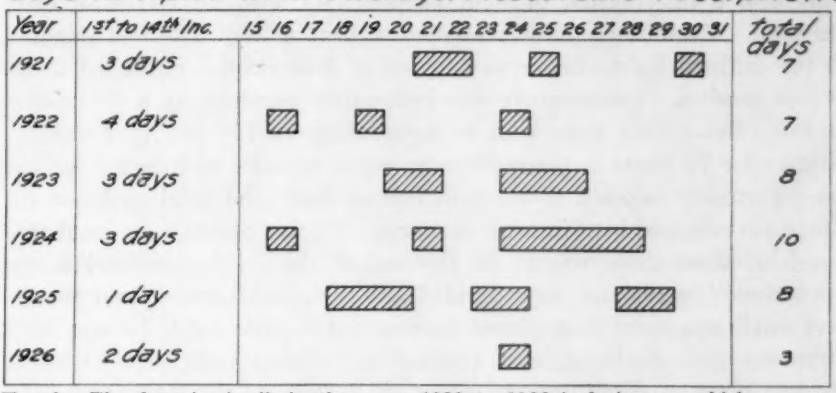

FIG. 2. The days in April, in the years 1921 to 1926 inclusive, on which an average measurable precipitation occurred throughout Minnesota.

measurable rainfall on only one day during this period in 1926. The month was ''by far the driest April in all the 36 years' record.''

In May, 1926, precipitation also was decidedly below normal, although the drought was not so pronounced as in the previous month. Since experiments with teliospores indicate that an approximately saturated atmosphere is necessary for about 12 hours previous to barberry infection, it seems reasonable to account for the ''light to moderate'' infection in Minnesota in 1926 (Table 4) on the basis of this April and May drought.

Local droughts also have been observed to affect barberry infection. Melhus *et al* (41) point out that the distribution of midsummer infection in northern Iowa appeared to be markedly influenced by the distribution of rainfall. Similarly, the combined observations of Mr. A. F. Thiel and Mr. H. A. Rodenhiser[10] in the spring of 1926, indicate that barberry infection in north-central Kansas was delayed by drought for a period of from two weeks to a month.

[9] See the Minnesota section of Climatological Data for May, 1924.

[10] Unpublished papers of Stakman *et al.*

Light.—In 1923 controlled experiments were made by Melander (40) and the writer, to learn something of the relation of light intensity to the infection of barberries and subsequent development of aecia. The telial material used for inoculum was on straw of *Agropyron repens,* and the rust was probably *Puccinia graminis secalis.* The experiments were made in a room where the only source of light was from several 1,000-watt nitrogen electric light bulbs spaced about 1½ feet apart on the ceiling and 6 feet above the plants.[11] The plants were set under the lights so as to allow as uniform a distribution of light as possible. Two intensities of light were used. The intense light measured approximately 270 foot candles, and the diffused light—under two layers of cheesecloth—measured about 200 foot candles. Temperature was kept fairly constant by a thermostat and fan. The plants were kept in approximately 100 per cent relative humidity for 72 hours in three different ways: exposed to constant intense light, alternately exposed to constant intense light and total darkness for 12-hour periods, and kept in total darkness. Twelve plants were incubated in each of these three ways. At the end of the incubation period, the three series of twelve each were divided into three small sets of four plants. These small sets were then placed in constant intense light, intense light alternating with darkness, and alternating diffused light and darkness. This was done to determine the effect of different light conditions, presumably after penetration had occurred. Table 6 summarizes the percentages of infection after 10 days of incubation. All of the plants were infected. Different amounts of light during the period of incubation apparently had no effect on the percentage of leaves infected, but the number of infected petioles was markedly greater on the plants kept in total darkness than on those exposed to constant intense light. After incubation, more intense light apparently increased the severity of infection both on leaves and petioles. The increased infection on petioles in the darkness was probably due directly or indirectly to etiolation. The higher degree of infection on plants exposed to intense light after incubation may have been correlated with metabolism in the host leaves. Probably neither effect was pronounced enough to influence the amount of infection in the field.

Liberation of Aeciospores

Although the forcible discharge of aeciospores in the rusts was described by Zalewski (67), in 1883, it was not until 1924 that Buller (10) described the discharge of aeciospores of *Puccinia graminis.* In still air they are

[11] The use of this room was made possible through the courtesy of Dr. R. B. Harvey, Associate Professor of Plant Physiology and Botany, University of Minnesota.

TABLE 6.—*The effect of different light intensities on the severity of Puccinia graminis secalis on Berberis vulgaris*

Light conditions during incubation in moist chambers	Light conditions after removal from moist chambers															
	Alternating intense light and darkness						Alternating diffuse light and darkness						Constant intense light					
	Serial no. of individual plants	Total no. leaves inoculated	Infected leaves		Infected petioles		Serial no. of individual plants	Total no. leaves inoculated	Infected leaves		Infected petioles		Serial no. of individual plants	Total no. leaves inoculated	Infected leaves		Infected petioles	
			No.	Per cent	No.	Per cent			No.	Per cent	No.	Per cent			No.	Per cent	No.	Per cent
Alternating light and darkness	31	26	14	53.8	11	42.3	33	48	20	41.7	12	25.0	26	25	17	68.0	12	48.0
	29	39	23	59.0	10	25.6	35	27	15	55.6	3	11.1	25	20	13	65.0	8	40.0
	32	61	42	68.8	7	11.5	36	75	35	46.7	5	6.7	28	39	20	51.3	5	12.8
	30	6	1	16.7	0	00.0	34	70	4	5.7	1	1.4	27	34	11	32.4	4	11.8
Totals	4	132	80	60.6	28	21.2	4	220	74	33.6	21	9.5	4	118	61	51.7	29	24.5
Constant darkness	19	14	14	100.0	9	64.3	24	21	18	85.7	12	57.1	14	13	11	84.6	10	76.9
	18	51	22	43.1	32	62.7	22	16	6	37.5	3	18.8	15	39	29	74.4	15	38.5
	20	15	6	40.0	8	53.3	21	14	11	78.6	2	14.3	16	30	11	36.7	5	16.7
	17	53	17	32.1	18	34.0	23	31	7	22.6	4	12.9	13	28	6	21.4	2	7.1
Totals	4	133	59	44.4	67	50.4	4	82	42	51.2	21	25.6	4	110	57	51.8	32	29.9
Constant light	11	42	39	92.8	18	42.9	10	36	17	47.2	13	36.1	8	19	8	42.1	5	26.3
	6	15	10	66.7	5	33.3	7	70	54	77.1	15	21.4	1	34	20	58.8	8	23.5
	9	37	23	62.2	3	8.1	3	22	1	4.5	2	9.1	5	22	16	72.7	3	13.6
	2	65	36	55.4	2	3.1	12	18	2	11.1	1	5.6	4	55	23	41.8	1	1.8
Totals	4	159	108	68.6	28	17.6	4	146	74	50.7	31	21.2	4	130	67	51.5	17	13.1

shot, on the average, 4–5 mm. from the aecial cup (10 and 15). They are discharged singly or in clumps and only in approximately saturated atmosphere. The maximum rate of discharge may be reached in an hour and a half after the cups are moistened (15). It is evident that the mechanism for the liberation of aeciospores facilitates wind dispersal.

Dissemination of Aeciospores

Earlier workers apparently did not distinguish between dissemination of aeciospores and the secondary spread of rust from urediniospores when tracing the development of local epidemics near barberries. Epidemics near barberries have been noted for nearly 200 years. During the latter half of the ninteenth century, aeciospores and the rust produced by them were assumed to be the source of infection for the whole neighborhood. Since the barberry eradication campaign has been in progress in the United States, numerous cases have been reported in which the rust had undoubtedly spread several miles. However, very few attempts have been made to determine the distance to which aeciospores spread from barberries.

The writer often has observed primary infection from barberries, but knows of only one case in which a large, heavily infected planting was found early enough in the season to distinguish between the primary infection due to aeciospores and the infection due to the spread of urediniospores. This was at Northfield, Minnesota. The planting was especially favorable for study: first, because it consisted of 175 large, severely rusted bushes, most of them 6 feet or more in height; second, because it was located on a deserted farmstead which was slightly higher than the nearby fields and was almost free of buildings and trees; third, because susceptible cereals and grasses were abundant in adjacent fields. Dr. J. J. Christensen[12] made some interesting observations on the spread of aeciospores from these bushes in the spring of 1922. The following data are taken from his summary. On May 18, when the bushes were first observed, the aecial cups were just beginning to open. A few days later there was an average of eight aecial clusters on each infected leaf. It was estimated that each bush produced at least 64,512,000,000 aeciospores, making a total of 11,289,600,000,000 spores. This estimate was very conservative, since it purposely did not take into consideration the elongation of aecial chains.

In order to determine how many spores were being deposited on surrounding fields, vaseline-coated glass slides, 1 inch by 3 inches, were exposed vertically about 3 feet from the ground at varying distances from the bushes. These slides, in addition to determining the number of spores, and the distances to which they were disseminated, made it possible to dis-

[12] Unpublished papers of Stakman *et al.*

tinguish the infection due to aeciospores from that due to newly formed urediniospores, by establishing the date when urediniospores were first disseminated. On May 24 and 25, when the slides were first exposed, the spores were being liberated at a tremendous rate. Several slides were exposed for 20 hours; one 3 feet from the barberry hedge caught approximately 160,000 spores; on another 6 feet away there were 33,000 spores; while on one 23 yards from the bushes there were 210 spores. A few days later, more than 3,000 aeciospores were caught on slides which were exposed for a week, at a distance of five-eighths of a mile from the bushes. A few aeciospores were caught on a slide exposed for 48 hours one mile from the bushes.

Because no urediniospores were found on the slides until June 2, it was assumed that all rust found on grains and grasses prior to and including June 6 was due to aeciospores only. A survey, made on that date by Dr. Christensen, Mr. G. D. George, and the writer to determine the extent of the infection, indicated that rust had spread more than a mile and a half from the barberries. It was heavy on volunteer rye and *Agropyron repens* for at least half a mile from the barberries, gradually decreasing as the distance from the bushes increased, until finally no trace of rust could be found on susceptible hosts. The infected area extended a mile west and north of the bushes and a mile and a half east, but only a few rods south. This peculiar shape of the rusted area was apparently due to the dissemination of spores by southeast and southwest winds.

The observable dissemination of aeciospores from the barberries was clearly limited to a two-mile radius from the bushes. Since these bushes were more heavily rusted and more favorably situated for disseminating spores than the average barberry planting, it seems probable that in the majority of cases observable primary infection from aeciospores is limited to the immediate vicinity of the bushes. Millions of spores were caught on the slides near the bushes, and there is evidence (56) that these spores may be lifted by the wind to elevations of several thousand feet. It is probable that aeciospores are disseminated many miles by the wind, but the infection centers which the individual spores cause are apparently too far apart to be found by the ordinary field survey.

Germination of Aeciospores

In 1865, De Bary (16) reported that aeciospores germinated very poorly. Since that time most of the investigators (15, 22, 35, 48 and 53) who have attempted to germinate aeciospores have experienced some difficulty, and concur in the opinion that the germination of the aeciospores of *Puccinia graminis* is remarkably capricious. Craigie (15), who has made probably the most extensive experiments, was not able to get uniform results. He

found that freshly discharged spores germinated in an hour and a half to two hours. The highest average germination took place in distilled water between 5° and 18° C. Very few spores germinated above 22° C. A few spores germinated after having been kept in the laboratory two weeks.

OVERWINTERING OF THE UREDINIAL STAGE

After the demonstration of heteroecism in the rusts by De Bary (16), certain investigators (1, 8, 42, 48, and 49) were inclined to believe the aecial stage necessary for the reinvigoration of the pathogene. Freeman and Johnson (24) proved that the sexual stage was not essential by culturing the uredinial stage through 52 transfers without any apparent loss of vigor. They also summarized the earlier work on the overwintering of the uredinial stage. The severe epidemic in 1904 first focused attention on the question of whether urediniospores may continue to propagate themselves in the Mississippi Valley.

Bolley and Pritchard (8) believed that field evidence did not preclude the possibility of overwintering occurring on the seed or as mycelium or spores on fall-sown grain or perennial grass hosts.

Seed Transmission of Stem Rust

Pritchard (51 and 52) found uredinia and telia of *P. graminis* on the inside of wheat kernels, and cites Smith as observing telia in oat seed in 1884. He believed the fungus overwintered in seed wheat, and concluded that "the mycelium from the pericarp penetrates various parts of the seedling, invading both the intercellular spaces and the cells. It soon passes into the spaces between the leaf sheaths, where it grows rapidly and attacks the tissues at various points. This peculiar mode of travel and attack may explain the failure of Eriksson and Ward to trace the fungous filaments beyond the immediate confines of the first appearing pustules, for these areas of infection may not spread while being carried up by the growth of the plant." He suggested that experiments should be made in which plants from infected seed be compared with plants from seed treated with Jensen's hot water treatment.

Hungerford (27) made careful experiments of this kind and was unable to demonstrate any difference in the amount of rust on plants from infected seed, inoculated seed, treated seed, and clean seed. His conclusions are as follows: "The results of experimental work here reported indicate that stem rust is not transmitted from one wheat crop to the next by means of seed grain. Further, in the writer's judgment, the occurrence of stem rust sori in the pericarp of the caryopsis of grains and grasses has no especial

significance, but the infection spreads to these tissues just as it does from an infection point in any of the vegative parts of the plant."

This method of overwintering does not seem likely and will not be considered further.

Overwintering in the Field

It has been known for nearly a quarter of a century that viable urediniospores of stem rust may persist throughout the winter in the Mississippi Valley. But there is a preponderance of evidence that they do not cause widespread infection on cereals in the spring in the Northern States.

During the winter of 1904–1905, Bolley and Pritchard (8) surveyed fields throughout the Mississippi Valley and made collections of fresh viable spores of *P. graminis,* at Dallas, Texas, December 25; and in December and January in Oklahoma, Kansas, Missouri, Mississippi, Illlinois, Wisconsin, Minnesota and North Dakota. He states that "Quantities of them (viable urediniospores) were being produced on winter wheat at Riverside, Illinois, . . . and a quantity of viable spores was taken from quack grass and wild barley frozen in ice at Fargo in March, 1905." In the winter of 1906–1907, Freeman and Johnson (24) germinated urediniospores of *P. graminis* from *Hordeum jubatum, Agropyron repens,* and *A. tenerum* throughout the winter and early spring months. Some of these spores, collected in the vicinity of St. Paul, Minnesota, germinated as late as April 15. But they never were able to obtain viable spores late enough in the spring to cause infection in the field. Similar results were obtained by Dickson and Johnson (18).

For the past eight years, 1918–1926, extensive studies have been made throughout the Mississippi Valley to determine the northern limits of overwintering in the uredinial stage.[13] These studies consist of germination tests, tests of the longevity of mycelium in wheat seedlings, and observations of primary infection in the spring. In general they indicate that, north of Oklahoma, primary infection of cereals as a result of local overwintering in the uredinial stage, occurs so rarely that it is probably of no practical importance. There is circumstantial evidence of overwintering in certain years in northern Texas and Oklahoma. It undoubtedly occurs in most years in a small percentage of fields of wheat and oats in the region around San Antonio, Texas. Although it is known (61) that *P. graminis phleipratensis* may overwinter in the Northern States, no evidence has been presented that the stem rusts of cereals overwinter on grasses and spread to grain in the spring.

It is not within the scope of this paper to present evidence for the geographic distribution of uredinial overwintering. We are interested rather

[13] Unpublished papers of Stakman *et al.*

in determining the conditions which establish this distribution. It is almost axiomatic that climatic conditions are responsible for confining overwintering to the south, but the specific conditions principally concerned are certainly not self-evident. The zone of demarcation between a region where stem rust overwinters frequently and the nearest region where it does not overwinter would seem to be the most favorable place to study this problem in the field.

It has already been mentioned that, with few exceptions, the northern limits of overwintering appear to be in northern Texas or Oklahoma. In this region an extensive survey was made in the winter of 1923–1924. Wallace Butler observed conditions around San Antonio, and Frank Frolik studied conditions in northern Texas and Oklahoma.[14] Stem rust of wheat overwintered in Butler's artificially inoculated plots at San Antonio and Austin and in a naturally infected field at Cliff, which is about 20 miles from San Antonio. Stem rust of oats also overwintered in the experimental plots of San Antonio and in a naturally infected field at Uvalde. Frolik examined 512 fields of wheat but was unable to find any evidence of overwintering. He obtained circumstantial evidence of abundant overwintering on volunteer oats in the vicinity of Elgin and Taylor, Texas. Farther north, at Temple, Waco, and West, the rust seemed to have overwintered in an occasional field of volunteer oats, but there was no evidence of overwintering on oats in the vicinity of Dallas and farther north. It was evident that conditions at San Antonio favored overwintering, and that the district around Dallas was the farthest south in which conditions were distinctly unfavorable for overwintering.

Butler charted the daily weather conditions at San Antonio, and Frolik charted and compared those at Dallas and San Antonio. Figure 3, A and B, gives the daily maximum and minimum temperature and the amount of precipitation at these two places for the period from June, 1923, to May, 1924, inclusive. There were two elements of difference between the weather at San Antonio and that at Dallas which seemed to have a bearing on the problem. In the first place, periods of alternate freezing and thawing occurred only three times during the winter at San Antonio, while at Dallas they occurred nine times. Secondly, there were no periods during which the mean temperature was over 65° F., accompanied by sufficient rainfall for infection, in the latter half of December, January, February, or early March at Dallas, while four such periods occurred at San Antonio. There was sufficient rainfall for spore germination on several occasions at Dallas in January and February, but as no fresh pustules appeared in February

[14] Unpublished papers of Stakman *et al.*

and March it was assumed that the temperature was too low for infection during these months.

These observations suggest that alternate freezing and thawing are critical conditions for stem rust. Under these conditions uredinospores germinate prematurely and the host leaves bearing the old pustules are killed. North of Oklahoma, artificial inoculation as a rule will not cause infection after September. In the central Mississippi Valley, periods of alternate freezing and thawing occur frequently throughout the winter and spring. In the Northern States, repeated germination tests have shown that urediniospores may remain viable throughout the winter but are eliminated in the spring, during periods of alternate freezing and thawing.[15]

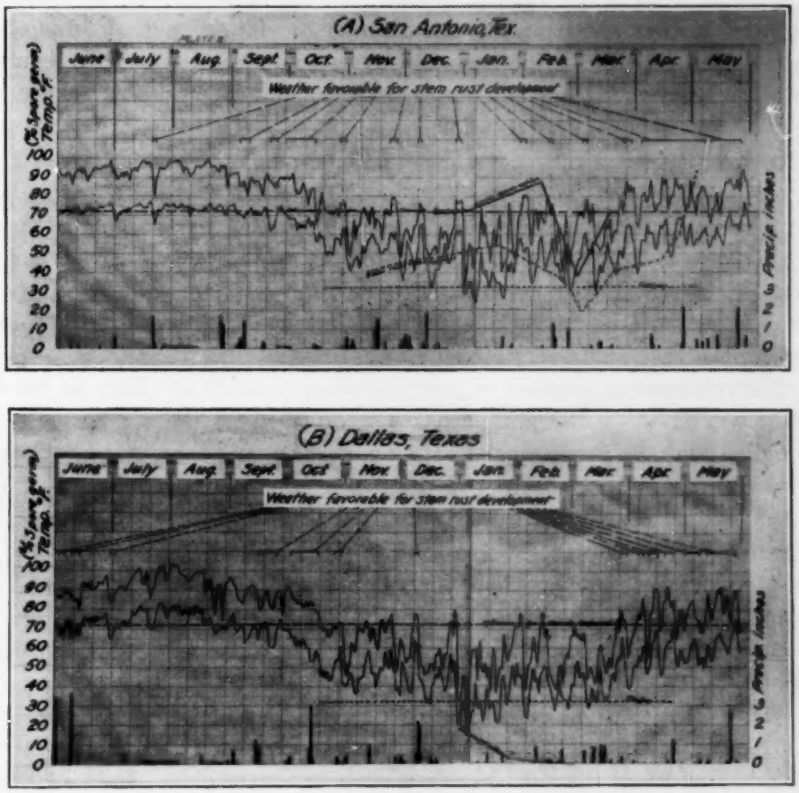

FIG. 3. Temperature range and amount of precipitation at (A) San Antonio, Tex., and (B) Dallas, Tex., from June 1, 1923, to May 30, 1924. Brackets indicate the periods favorable for stem rust development, *i.e.*, periods during which the mean temperature was between 65° and 78° F., accompanied by abundant precipitation.

[15] Unpublished papers of Stakman *et al.*

Weather conditions during the previous growing season also may affect overwintering by determining the amount of inoculum present in the fall, or the condition of the host. There is very little evidence of overwintering north of Oklahoma, in spite of the fact that inoculum usually is plentiful in the fall. Therefore conditions during the previous growing season are probably not important in the Northern States. In the Southern States inoculum is not always present in the fall. This is especially true in central and southern Texas. For several years Butler has shown by inoculation experiments that stem rust will overwinter at San Antonio when inoculum is present in the fall.

On the other hand, field observations indicate that the rust overwinters in only one field in a hundred in this region. It is difficult for uredinial infection to persist on grass hosts through the latter part of June, July, August, and September, during which period no grain is present because of the early harvest and late fall sowing. These are hot months in Texas, and there is usually little precipitation until October. The grasses dry up early in the summer, except for a few green patches along the stream beds. There is some evidence that local oversummering occurs in situations of this kind, but it has never been clearly demonstrated that stem rust spreads from susceptible grasses to grain in the fall in Texas. It is not clear whether fall infection occurs as a result of local oversummering or wind-blown spores, but it is certain that, in the San Antonio area, oversummering is more difficult for the rust than overwintering.

The influence of weather on overwintering through its effect on the host plant as well as on the pathogene is exemplified by the conditions which brought about the predominance of stem rust on oats over that on wheat in northern Texas and Oklahoma in the season of 1925–1926. In the opinion of the writer this situation was due to a peculiar chain of circumstances beginning in the winter of 1924–1925, which were unusually favorable for the development and persistence of volunteer oats. In the spring of 1925, because of a drought, most of the oat crop was not worth cutting. It was pastured off, and the cattle trampled the seed into the soil, where it remained until fall. Early fall rains favored the germination of this seed.

With the exception of two cold weeks in October, the winter of 1925–1926 was extremely mild in northern Texas and Oklahoma. Volunteer oats flourished and was the most vigorous crop in that region. Uniform stands were obtained and most of the fields were allowed to grow to maturity. They were infected in the fall and apparently furnished ideal conditions for the overwintering and early spring development of stem rust. Incidentally, a heavily rusted field of volunteer oats was found in June, 1926, near Enid,

in northern Oklahoma, which strongly suggested overwintering. The wheat situation, on the other hand, was in direct contrast with this condition. Volunteer wheat was scarce in Oklahoma, probably because of loss of viability of the seed during the hot summer months, and winter wheat was delayed by cold weather in October and apparently was not infected in the fall.

Thus it appears that stem rust of oats predominated over that on wheat in the spring of 1926, because conditions which prevailed in northern Texas and Oklahoma during the winter of 1924–1925, the spring and summer of 1925, and the winter of 1925–1926, continued to favor the development of volunteer oats but were not especially favorable for volunteer wheat.

DISSEMINATION OF UREDINIOSPORES

All of the spore forms of stem rust except the teliospore are adapted to wind dissemination. The sporidia and aeciospores are shot away from the host, while the urediniospores accumulate in a powdery mass in the sori until they are picked up or shaken off by the wind. Observations on the spread of rust from centers of primary infection in wheat fields, and on the spread of rust from infected grain near barberries, have given direct evidence that urediniospores may be disseminated several miles. There is strong circumstantial evidence that viable urediniospores may be transported several hundred miles. Local dissemination of spores that actually can be traced from their source will be considered first.

Local Dissemination

Field observations indicate that a considerable quantity of uredinial inoculum must accumulate before stem rust migrates in perceptible amounts from one field to another. This is illustrated by the spread of rust from individual pustules in the general primary infection in the spring wheat area, from spot infections in Oklahoma, Missouri, and Illinois, and from overwintering centers in southern Texas.

For the past six years, 1920 to 1926, a general primary infection has appeared in June almost simultaneously in practically every wheat field over a large part of the spring wheat area. In most fields this infection consists of single pustules on less than 1 per cent of the plants. The development of rust centers from these single pustules has been studied on several occasions, and small areas developed from them have been repeatedly found in all stages of development. On the average, these areas develop as follows:

First generation—single pustules on leaves or culms of plants, from 3 feet to a rod apart in the field.

Second generation—several fresh pustules near the old pustule, usually on the same plant, with possibly one or two pustules on adjacent plants.

Third generation—several culms with 1–5 per cent infection, each plant within a 2-foot radius having one or several pustules, usually on the side of the culm toward the old infection.

Fourth generation—heavily rusted areas coalescing but usually still discernible, average infection 1–5 per cent throughout the field.

Fifth generation and sixth generation—infection practically uniform throughout the field.

Since infection becomes more or less uniform in the spring wheat area after the fourth generation, it is impossible to determine in that region the size that isolated centers of infection might attain. However, in Texas, Oklahoma, Kansas, Missouri, and Illinois, isolated infection centers often develop. These sometimes become rather large without materially influencing the amount of infection outside of the immediate vicinity of the rust center. A few examples will serve to illustrate the nature of this infection.

Perhaps the most striking cases were found by Butler[16] in 1922 in Kansas and Missouri. In a field of wheat at Parsons, Kans., June 4, a spot about 20 feet across was discovered in which infection ranged from 1 per cent to 25 per cent on practically all plants. Twenty feet from the edge of this area no rust could be found, nor was any rust found in a search through a half-mile of the field. There were no peculiarities in the topography of the field which would explain the limited size of the rust spot. After examining plants for some time in a nearby field, a second spot was discovered, slightly larger, with about 25 per cent severity in the center and light infection at the edges. A careful search failed to reveal any stem rust at other points. In the next three days similar spots were found at Clinton, Newburg, and Springfield, Mo. By June 8, when the spot was found at Springfield, traces of stem rust were beginning to appear in most wheat fields in northern Missouri, but the rust had not developed further than the second generation outside these rust spots. The severity and prevalence of the rust was determined in a field containing a typical spot near Springfield. In this field there was about 25 per cent severity inside an area 10 feet in diameter; 25 feet from this area, an average of four pustules on 40 per cent of the plants; and in the most remote part of the field, from one to three pustules on 12 per cent of the plants.

In 1924, Frank Frolik and the writer found rust areas 10–15 feet in diameter near Dallas and Denton, Tex. In 1925, William Walker and the

[16] Unpublished papers of Stakman *et al.*

writer found numerous spots 2–6 feet in diameter on oats in northern Texas. The same year spots 2–15 feet in diameter were found by Frolik in Gallatin and Saline Counties in Illinois.

In all these cases the limits of the infected areas were quite distinct, indicating that stem rust usually spreads slowly for the first four or five generations, until a heavily rusted area is developed 5–10 feet in diameter, which usually contains sufficient inoculum to cause a noticeable infection over several acres. When rust has become plentiful in an entire field, it may spread to surrounding fields, at least within a radius of from one to several miles. Evidence of this has been found in Texas and Oklahoma and near barberries in the Northern States.

On June 2, 1922, a field of wheat was found near Denison, Tex., in which stem rust infection averaged 50 per cent on all plants. Here the rust had apparently already spread to four other fields within a mile of this field, since there was between one-half and one-fourth as much infection in these fields. The infection tapered off as the distance from the heavily rusted field increased.

A similar center of infection was found in a field of oats near San Antonio, Tex., in 1923. On May 1, there was a 50 per cent infection on most plants over a considerable portion of this field. Another field a hundred rods away contained from a mere trace to 5 per cent. A careful search was made in 20 fields of oats which were located from 2 to 20 miles from this field. Two pustules were found in one field and none in the others.

In 1924, stem rust overwintered in a mixed field of Kanred and Arnautka (Nicaraugua) wheat near Cliff, Tex. Cliff is less than 25 miles from San Antonio. On March 27 there was a trace of rust on approximately 1 per cent of the plants. On April 8 rust had not yet spread to two fields which were located within a mile of this field. By May 10 the rust in the former field had reached a severity of 10–40 per cent on most plants. In a field 40 rods away the plants nearest the heavily rusted field had from 1 pustule to 10 per cent of rust on them; 60 rods farther only traces of rust were present. On May 16 the first field was in the hard dough stage, and an average of 75 per cent rust had developed in it. On this date a field of the same variety a mile east contained no more than a trace or 1 per cent rust. At harvest time, June 1, the wheat in the field in which stem rust had overwintered was lodged, because of the extremely heavy rust infection; a 40 per cent infection had developed on the near side of the field 40 rods away, the infection tapering off to 3 per cent on the opposite side of the field; and in a field of the same variety, one mile east, the rust had increased

to between a trace and 2 per cent. Spot infections were found in several wheat fields along the road from Cliff to San Antonio.

An excellent example of rust spreading for several miles from a heavily infected field to surrounding territory was observed by the writer near Enid, Oklahoma, June 9, 1924. Numerous spots of rust in the third generation were found in a 30-acre field 9 miles south of Enid. This field proved to be in the center of a rusted area. There were traces of rust in fields as far as 3 miles south of the heavily rusted field and 6 miles north, but outside of this area no rust could be found. Previous to June 9, two weeks had been spent searching in vain for stem rust in southern Kansas and northern Oklahoma.

After discovering the rusted area, a careful survey failed to reveal any stem rust along the Meridian Highway between Enid, Okla., and Wellington, Kans., a distance of 40 miles. Butler, who drove north from Texas on this same road a few days earlier, found rust in southern Oklahoma, at Duncan, but could not find it in 21 fields between Duncan and El Reno. These observations leave little room for doubt that the rust had spread at least 3 miles south and 6 miles north from the one heavily rusted field near Enid.

Some of the best evidence of local epidemics due to wind-blown urediniospores from heavily rusted fields may be found in the secondary spread of rust from barberries. The epidemic near the barberries at Northfield, Minn., may be used again as an illustration. It will be recalled that on June 6 uredinial infection, due to the dissemination of aeciospores, had spread 1½ miles from the barberries and covered an area of about 2½ square miles. On June 12, urediniospores from this area, reinforced by newly formed aeciospores, had spread rust over an area covering about 6 square miles. By June 18 the heavily rusted area of rye and *Agropyron repens* included 12 square miles, and on July 10 it included approximately 40 square miles. By that time the epidemic from the planting at Northfield had coalesced with rust spreading from six smaller plantings which were found nearby.

This positive evidence of the spread of rust over 40 square miles in a few weeks raises the question of how far rust may spread from such an area.

Regional Dissemination

The diffused nature of the primary infection in the spring wheat area suggests a remote source of inoculum.

In 1911, Freeman and Johnson (24) suggested the possibility of rust migrating from Texas northward. Gassner (25) postulated a similar

migration of spores in South America. Recent field studies[17] indicate that two sources of inoculum are usually present which might account for the primary infection in the spring wheat area, namely, urediniospores in Texas, and local epidemics near barberries in the Northern States. It is not within the scope of this paper to discuss which of these two sources is the more important. It is desired merely to point out that in wind dissemination there is a mechanism which can explain a wide-spread dissemination from either source. Stakman *et al.* (56) recognized the possibility of spores being carried into the air by convection currents, whirlwinds, and other air movements. They exposed glass slides, coated with vaseline, from aeroplanes and caught spores and pollen grains at altitudes up to 10,000 feet, and germinated urediniospores collected at elevations of 1,000 to 7,000 feet. Tremendous numbers of spores were caught on slides exposed over the spring wheat area during the epidemic of 1922. One slide exposed for 2¾ hours at altitudes from 1,000 to 5,000 feet caught more than 3,000 stem-rust urediniospores.

The distance which spores may be carried would seem to depend on the rate of fall of the spores and the velocity of the wind. Buller (10) estimated the rate of fall of basidiospores at 1–3 mm. a second, and McCubbin (36) estimated the rate of fall of urediniospores of *Cronartium ribicola,* which are approximately the size of stem-rust urediniospores, at 8 mm. a second. The rate of fall of urediniospores of *Puccinia graminis* has not been determined, but from what is known of dust movement it seems probable that the ordinary circulation of the air is sufficient to keep them suspended almost indefinitely. Free (23) states that Ulden observed the paths of quartz particles of various sizes allowed to fall freely through a wind blowing with a velocity of approximately 8 miles an hour. It was found that particles averaging 0.75 mm. in diameter fell in a path differing but 10 degrees from the vertical.

Those averaging 0.18 mm. followed a path differing but little from the horizontal. Material 0.08 mm. and less in diameter was blown clear away. Free (23) has tabulated the maximum size of dust particles in the Sirrocco dust blown into Europe from the Sahara desert and found that, in the average dust storms, particles were more than 50 μ and in some cases 200 μ in diameter. The dust which was blown from Australia to New Zealand, 1,500 miles, in 1903, contained particles 30 μ in diameter, approximately the length of a urediniospore. From data obtained by collecting dust in storms occurring previous to 1896, Ulden estimated that 1,225,000,000,000 "mile tons" of dust transfer was accomplished annually in the western States of the United States (23).

[17] Unpublished papers of Stakman *et al.*

These dust storm analogies indicate that the wind is perfectly capable of carrying spores thousands of miles if sufficient spore material is present. According to Meisinger (38), the United States Weather Bureau is just beginning to study the free air trajectories of layers of air higher than the surface, 500–1,000 feet. Is there any direct evidence that winds ever occur which, for example, may transport spores from Texas, where overwintering and early development occur, to the spring wheat area?

The national balloon race, which was held in the Mississippi Valley in 1924, shows how spores may be blown from south to north in this region. Seven balloons started from San Antonio, Tex., in the late afternoon of April 23, 1924. Four of them traveled over 1,000 miles; two landed in southern Minnesota, and two in Iowa. The longest trip was made by Van Orman from San Antonio to Rochester, Minn.

The distance, 1,072 miles, was covered in 44 hours. Peek made somewhat better time than Van Orman, traveling to St. Ansgar, Iowa, a distance of 1,021 miles, in 32 hours and 27 minutes. Air currents at an altitude of 500 to 1,500 meters were used for the larger part of the race, although altitudes up to 5,000 meters were used on one occasion by Van Orman to prevent his balloon from being drawn into a Low. The distances traversed by these balloons, and the rate of travel, are interesting in themselves, but the fact that the balloons started at San Antonio, Tex., and landed in the spring wheat area makes the flights more significant, and suggests that they may furnish a clue to the weather conditions conducive to strong south winds in the western Mississippi Valley.

Jakl (30) has analyzed the weather conditions which existed during the flights. He states, "The winds observed at about the time the balloons took off were steadily southerly, becoming southwesterly at 2,000 meters from Texas, north to North Dakota. Velocities in a southerly current averaged about 30 miles per hour, being the highest about 1,000 meters above the ground, and higher over the northern sections than in the south." These strong southerly winds were attributed by Jakl to the presence of a High over the southeast States, and a Low which extended over the plateau region just east of the Rocky Mountains. This condition, as illustrated in figure 4, persisted throughout April 23 and 24, the days on which the balloons were in the air. The relation of the High in the east and the Low pressure area in the west, to the winds between them, will be fully appreciated when it is recalled that air circulates in a clock-wise direction about a High and a counter-clock-wise direction about a Low.

It has been shown, by exposing slides from an aeroplane, that in some years spores are abundant in the air over central and northern Texas in

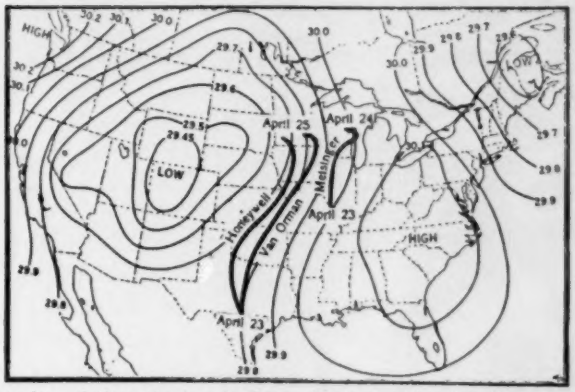

FIG. 4. Trajectories of the winning balloons in the national balloon race of 1924, and the pressure distribution in the evening of the day on which the race started, April 23, 1924. (After Meisinger.)

May. For example, on May 18, 1922, approximately 400 stem rust urediniospores were caught during a flight from San Antonio to Dallas, Texas. These spores were caught at altitudes ranging between 1,000 and 2,000 feet.[18]

To determine whether atmospheric conditions, similar to those mentioned above, exist in late May or early June, the writer examined the Daily Weather Maps for the period from 1901 to 1926. As indicated in table 7, conditions comparable to those shown in figure 4, that is, a High in the east and a Low in the west, separated by approximately straight isobars from the Gulf of Mexico to Canada, occurred from one to several times during the last ten days in May and the first ten days in June in every year for the past 25 years. There is no indication of a correlation between the years in which conditions seemed to be the most favorable for the migration of rust from the south to the north and the years in which epidemics developed in the spring wheat area. But it is clear that southerly winds often sweep up the Mississippi Valley at the time the rust is most plentiful in the south, with sufficient velocity to carry spores from Texas to the spring wheat area in less than three days.

It might be objected that these balloons traveled at altitudes higher than those in which urediniospores are abundant, or that the spores would diffuse to such an extent that only a few would ever reach the spring wheat area. That these objections are not necessarily valid is indicated by the distribution of smoke from Minnesota forest fires in 1918. Lyman (34) summarized the observations on the paths of these smoke clouds and showed

[18] Unpublished papers of Stakman *et al.*

TABLE 7.—*Days on which conditions seemed favorable for winds to blow spores from Texas to the spring wheat area, i.e., with a HIGH in the East and a LOW in the West, during the period May 20 to June 10, from 1901 to 1926 inclusive*

Year	May												June									
	20	21	22	23	24	25	26	27	28	29	30	31	1	2	3	4	5	6	7	8	9	10
1901	0	0	0	0	0	0	0	0	0	0	0	0	0	0	+	0	0	0	0	0	+	0
1902	+	0	0	0	0	0	0	0	0	0	+	+	+	0	0	0	0	0	0	0	0	+
1903	0	+	+	0	+	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1904	0	+	+	0	+	0	0	0	+	0	0	0	0	0	0	0	0	0	0	0	+	0
1905	0	0	0	0	0	0	0	0	+	0	0	0	+	0	+	+	0	0	0	+	0	0
1906	0	+	0	0	0	+	0	0	0	+	0	0	0	+	+	+	0	+	0	0	0	0
1907	0	+	+	0	0	0	0	0	+	0	0	0	0	0	0	0	0	+	+	0	+	0
1908	+	0	0	0	0	0	0	0	0	0	0	0	0	+	+	+	+	+	0	0	0	0
1909	0	0	0	0	0	0	0	0	+	+	+	0	0	0	0	0	0	0	0	0	0	0
1910	0	0	0	0	0	0	+	+	+	0	0	0	0	0	0	0	0	0	0	+	+	0
1911	0	0	0	0	+	0	+	0	0	0	0	0	0	0	+	0	0	0	0	+	+	+
1912	0	0	0	0	0	0	+	+	0	+	0	0	0	0	0	0	0	0	0	+	+	0
1913	0	0	0	0	0	+	0	+	+	0	0	0	0	0	0	0	+	0	0	0	0	0
1914	+	0	0	+	+	+	+	0	+	0	0	0	0	+	+	+	+	+	+	0	0	+
1915	0	0	0	0	0	+	0	0	0	0	0	0	0	0	0	+	0	0	0	0	+	0
1916	+	0	0	0	0	+	0	0	0	0	0	+	0	0	0	0	0	0	0	0	0	0
1917	0	0	0	0	0	+	+	0	0	0	0	0	0	0	+	0	0	0	0	0	0	+
1918	0	+	0	0	+	0	0	0	0	0	+	+	0	0	+	0	+	0	0	+	0	0
1919	0	0	0	0	0	0	0	0	0	0	+	+	0	0	0	0	0	0	0	0	0	0
1920	0	+	+	0	0	0	0	0	0	0	0	0	0	0	0	0	0	+	0	+	+	+
1921	+	+	0	+	0	0	0	0	0	0	0	0	0	0	0	0	0	+	0	+	0	0
1922	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	+	+	0	0	+	0	0
1923	0	0	0	0	0	0	+	+	0	0	0	+	+	0	0	0	0	0	0	+	+	0
1924	0	0	0	0	0	0	+	0	0	0	0	0	0	0	0	0	0	0	0	+	0	0
1925	0	0	+	0	0	0	+	0	0	+	+	+	0	0	0	+	0	0	+	0	0	0
1926	0	0	0	+	+	+	0	0	+	0	0	0	0	0	0	0	0	0	0	0	0	+

that they were blown from Minnesota to New York and along the Atlantic Coast to South Carolina in two days. The smoke was not diffused but was disseminated in clouds dense enough to lower the visibility at points along their paths. That it was largely in the lower strata of air is indicated by the fact that the odor of burning wood was recorded in most of the localities where the smoke was seen.

GERMINATION OF UREDINIOSPORES AND UREDINIAL INFECTION

Germination.—Factors affecting the functioning of urediniospores have been studied both in the laboratory and in the field. There is experimental evidence that they will germinate in a wide range of temperature and are

comparatively long-lived especially at low temperatures. It has already been pointed out that the low minimum for spore germination is probably detrimental rather than beneficial, as the minimum temperature for penetration is comparatively high, and germination frequently takes place when the germ tubes are unable to penetrate.

Johnson (31) determined the minimum and maximum temperature for the germination of *Puccinia graminis* at 1.5° to 32° C. Hursh (28) obtained excellent germination at 10°, 20°, and 30° C. with two forms of *P. graminis tritici.* Form 11, of Stakman and Levine (60), which is the more virulent of the two, seemed more tolerant of the higher and lower temperatures than form 27.

De Bary (16) showed that urediniospores retain their viability two months if kept dry. Urediniospores germinated in Bolley's (7) cultures after being exposed to sunlight on glass slides during the month of August. Peltier (46) has shown that urediniospores may retain their viability at a low temperature (5° C.) in moderate relative humidity (49 per cent) for a year or more.

Infection.—Stakman and Levine (59) state, "The most favorable temperature for shortening the incubation period, hastening the maturing and obtaining vigorous infection, appeared to be between 66.5° and 70° F. (19° and 21° C.)." In Peltier's (45, 47) cultures the optimum temperature for the development of stem rust with *Puccinia graminis tritici* forms 3 and 19 of Stakman and Levine on wheat in the seedling, stooling, and jointing stages was between 20° and 25° C. No penetration occurred at temperatures of 15° C. and below, except on Arnautka and einkorn, which were infected at 10° C. The minimum temperature suitable for penetration was about 5° C. lower for form 9 than for form 3. Only a few plants of a limited number of varieties were infected at 30° C. The minimum time for penetration was about 3 hours; fair infection developed after 6 hours, and there was a maximum penetration in 36 hours. The period of incubation was prolonged for nine weeks by submitting the inoculated plants to low temperatures. Both Stakman and Levine (59) and Peltier (47) agree that light is not essential for penetration, but is necessary for rust development, inasmuch as the host plant is dependent upon light for vigorous growth.

Field observations also have been recorded which seem to have a bearing on this problem. Mehta (39) inoculated wheat on successive days in the spring at Cambridge, England, and determined that the incubation period was shortened as the season progressed and the mean temperature increased. At a mean temperature of 40° F. the incubation period was 22 days; at 50.8° it was 15 days; at 54.1°, 12 days; and at 66.5°, 9 days. Tehon and

Young (62), in 1923, noted a coincidence between the occurrence of primary infection in Illinois and a mean temperature of 71.5° F. preceded by abundant rainfall. They believed this to be a causal relationship. Beauverie (2) noted that no stem rust developed in the experimental gardens at Limagne and Clermont in 1921, while it was abundant in 1922. This he attributed to the fact that in 1921 there was no rain from the first ten days in June until harvest, while rainfall was frequent and often abundant during the same period in 1922.

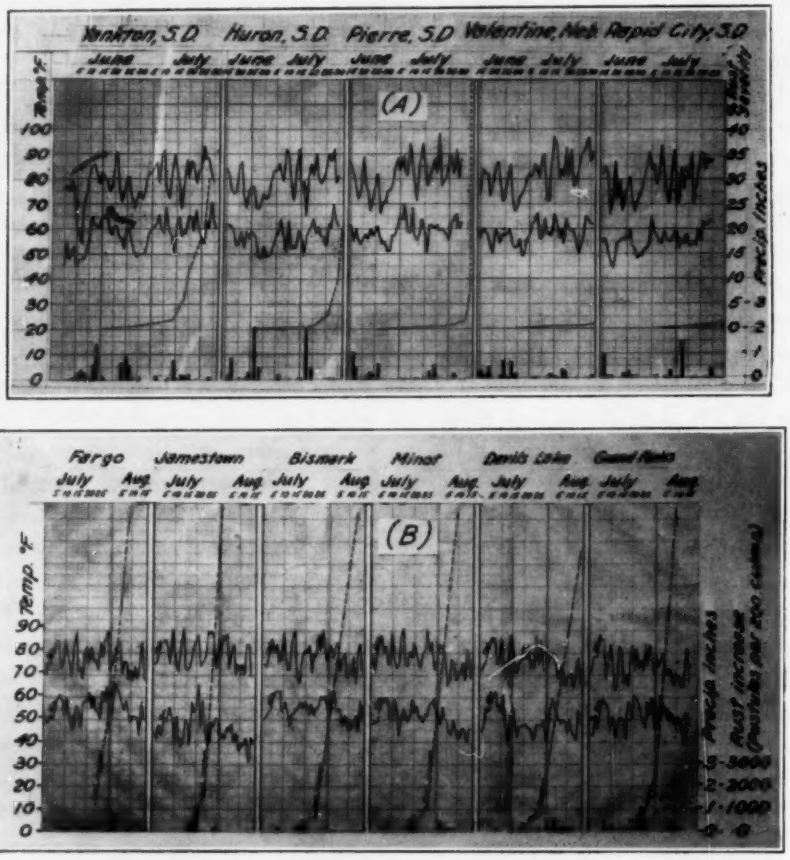

FIG. 5–A. Relation of stem rust development to the temperature range and amount of precipitation at Valentine, Nebraska, and at Yankton, Huron, Pierre, and Rapid City, South Dakota, in June and July, 1924.

B. Relation of stem rust development to the temperature range and the amount of precipitation at Fargo, Jamestown, Bismarck, Minot, Devils Lake, and Grand Forks, North Dakota, in July and August, 1924.

In 1924, repeated observations were made to determine the relation of weather conditions to the rate of development of stem rust at several points in Minnesota, South Dakota, and North Dakota.[19] Figure 5, A and B illustrates the rust development, together with the temperature range and the amount of precipitation at the different stages, in North Dakota and South Dakota. Two different methods were used for recording the rust; in South Dakota the percentage of rust severity, and in North Dakota the number of pustules on 200 culms. As indicated in the figures, the inoculum increased at so tremendous a rate as the season progressed that it complicated the problem to such an extent that no definite conclusions could be drawn.

THE DEVELOPMENT OF DESTRUCTIVE EPIDEMICS

Destructive epidemics occur periodically in the spring wheat area. Several attempts have been made to determine the relation of seasonal weather conditions to the development of these epidemics. Some investigators regard the effect of weather on the rate of growth of the host as the most important; others emphasize the effect of weather on the development of the pathogene.

Certainly both must be considered, since a destructive epidemic involves a race between the pathogene and the host.

There can be little doubt that the vigor and rate of growth of wheat is affected by seasonal variations in temperature and precipitation. Hutcheson and Quantz (29) grew small grains at 58°, 62°, 65°, and 75° F. and considered the optima to be 62° F. for wheat (Fulcaster), 65° to 75° F. for oats (Culberson), 58° to 62° F. for barley (Union Winter), and 62° F. for rye (Abruzzes). Peltier (47), as a result of experiments in the greenhouse, considered 15° to 20° C. the best temperatures for the development of the seedling, stooling, jointing, and heading stages of several wheat varieties, including certain spring wheats. In his experiments, temperatures below 10° C. resulted in slow growth, and likewise temperatures above 25° C. inhibited growth.

Five years' records[20] of the date of sowing and heading in the rust nurseries at St. Paul, given in table 9, indicate that in 1924 the period between sowing and heading was delayed considerably by low temperatures in May and June.

Blair (3, 4, and 5) has shown that low temperature during the growing season is correlated with high yields of winter wheat in Ohio and spring

[19] In North Dakota the development of the rust was observed by Frolik, while in South Dakota and Nebraska observations were made by Butler.

[20] These were furnished by Dr. Olaf S. Aamodt, formerly Associate Pathologist, Office of Cereal Crops and Diseases, U. S. Department of Agriculture.

TABLE 9.—*The relation of mean temperatures to the length of the growing period of Marquis wheat in the stem rust nursery at St. Paul, Minnesota, during the period 1920 to 1924 inclusive*

Year	Date of sowing	Date of heading	No. days from sowing to heading	Mean departures from normal temperatures[a]		
				May	June	Average
1920	April 29	June 28	59	+0.8	+0.6	+0.70
1921	April 25	June 24	59	+1.6	+6.1	+0.37
1922	April 24	June 21	57	+4.6	+1.2	+2.90
1923	April 25	June 25	60	+0.7	+2.9	+1.80
1924	April 24	July 8	75	−8.1	−3.5	−5.80

[a] The normal temperatures as given in the Monthly Weather Review are 58.2° F. for May, and 67.4° F. for June.

wheat in North and South Dakota. Low mean temperatures in June and abundant precipitation in May and June were correlated with high yields of spring wheat in North and South Dakota.

Sorauer (54) reviewed the earlier European literature on the relation of weather to the development of cereal rusts, and was of the opinion that weather conditions, such as sudden changes in temperature, would predispose the host plants to rust.

Carleton (12) attributed the abundance of rust in the spring wheat area in 1904 to: "(1) The fact that there was an unusual quantity of moisture just at the proper time for rust to do the most damage to the crop, and (2) the unusual delay in ripening the grain." He considered the period between the date of blossoming and the date of ripening the critical time, because rust was plentiful in the field at that time and because rainfall tended to make more succulent growth and delay maturity.

Freeman and Johnson (24) also emphasize the importance of the grain maturing as early as possible to escape damage from rust. They believe the critical period for wheat with respect to attacks of *Puccinia graminis* is heading time, a period of ten days for any one locality. They state, "If for any reason this period is delayed or lengthened, the number of urediniospores falling on each plant is very considerably increased. Infections have a longer time in which to develop and the danger of an epidemic is imminent. They analyzed the relation of precipitation and temperature to the development of rust in the years 1903, 1904, and 1905. During these years there was least rust in 1903, a severe epidemic in 1904, and a moderate amount of rust in 1905. The greatest precipitation occurred in 1905,

whether we consider a seven-months' period preceding harvest, a three-months' growing period, or the month containing the "critical period." Since 1904 was the epidemic year, precipitation was not considered to be the most important factor. From the temperature records they conclude, "That although the general average of temperatures for the whole area for seven-month and three-month periods (preceding harvest) in 1903, 1904, and 1905 were not much different, still in those states where the rust was most severe in 1904, namely, Minnesota, North Dakota, South Dakota, Iowa and Wisconsin, temperatures for the seven-month period averaged much lower in 1904 than in 1905, and for the three-month period averaged about the same as in 1905.

"During the one-month period temperatures were consistently subnormal in 1904, averaging 2.67° below normal for the whole region; temperatures were 3.5° below normal over South Dakota, North Dakota, Minnesota, and Wisconsin; this average being considerably lower than that of either 1903 or 1905. It is seen, then, that the unusual low temperature over this region was a very important factor, if not the determining factor, for the prevalence of rust in 1904. Low temperatures made the crop as a whole late." Bolley (7) also believed that dew and cool temperatures favored the development of rust in 1904.

Cotton (14) is inclined to stress the effect of weather on the pathogene. He accounted for a less serious attack of stem rust in southern England in 1920 than in 1919 on the basis of, first, the infection as a whole being less extensive, and second, the cool weather previous to ripening tending to check the growth of the mycelium in the tissues, and to prevent excessive evaporation following the splitting of the cortical tissues of the stem.

Walster (64) divided the growing season for wheat at Fargo, North Dakota, into nine periods of 10 days each, and compared the maximum and minimum temperatures and precipitation of each period, in five epidemic years, with those of similar periods in five non-rust years. He concluded that high temperature and abundant precipitation were correlated with the occurrence of rust epidemics.

Levine (33) found an apparent positive correlation between the combined mean temperature and precipitation in the month of June and the percentage of rust at the end of the growing season, in "uniform rust nurseries" at St. Paul, Minn., Mandan and Dickson, N. Dak., and Akron, Colo., in the years 1919 to 1923 inclusive. An attempt also was made to determine if there was a correlation between mean temperature and total precipitation during the last two months of the growing season and stem rust infection at harvest time, on three varieties of wheat growing in numerous rust nurseries throughout the Mississippi Valley and in Mani-

toba, Saskatchewan, and Alberta, Canada. Correlations were made with 264 varietal units in 89 nursery years. A coefficient of correlation of $+0.283 \pm 0.038$ was obtained for temperature and rust infection, and $+0.336 \pm 0.037$ for total precipitation and rust infection; at the same time there was no apparent correlation between temperature and rainfall. No infection whatever occurred where the total rainfall was below 2 inches or where the mean temperature was less than 60° F. Barring one exception, not more than 40 per cent rust occurred at or below 62° F. From 90 to 100 per cent rust was found only at the mean temperature range of 66° to 72° F., coupled with a total rainfall exceeding 2.5 inches. The multiple correlation between these two weather conditions and the severity of stem rust infection was +0.4239. Levine states, "These results would justify the conclusion that in the final analysis weather conditions during the last two months of the growing season play only a minor, even if very important, part in the intenseness of stem rust epidemics. "Stakman and Lambert (58) briefly summarized observations which point toward a correlation between warm growing seasons and epidemics in the spring wheat area.

Epidemics in the Spring Wheat Area

The writer has studied the relation of seasonal weather conditions to the occurrence of destructive epidemics in the spring wheat area during the period 1904 to 1925 inclusive. The historical method was used. The months of May, June, and July were considered most important in the spring wheat area because these months are the growing season for spring wheat, and because barberries become infected in May, and rust is spreading from barberries and multiplying in grain fields in June and July. The following factors were considered: mean monthly temperatures, total monthly temperatures, total monthly precipitation, the number of rainy days, and the number of clear days. All weather records, unless otherwise stated, were taken from Climatalogical Data of the United States Department of Agriculture Weather Bureau. Since temperature seems to be the most important factor, its relation to epidemics was also studied in the Southern and Central States. The first step was to classify the years according to the amount of rust which developed in them.

The epidemic of 1904 first focussed attention on stem rust as a limiting factor in the production of grain in the spring wheat area. Carleton (12) characterized this epidemic as follows: "Probably the most severe attack of rust ever known in that region, certainly the most severe in the last 20 or 25 years, occurred during that season." Since that time state patholo-

gists and other cereal investigators have kept fairly complete records[21] of the relative severity of epidemics.

It is apparent from these records that, during the past quarter century, the worst epidemics occurred in 1904, 1911, 1916, 1919, 1920, and 1923. There was comparatively little rust in 1907, 1909, 1910, 1912, 1913, 1915, 1918, and 1924. During the remaining years, 1905, 1906, 1908, 1914, 1917, 1921, 1922, and 1925, the rust was intermediate or indeterminate. For purposes of comparison, the first series will be designated epidemic years, the second series non-epidemic, and the third series intermediate. The approximate differences in the amount of rust from year to year are illustrated diagrammatically in Figure 6. In most of the comparisons the intermediate

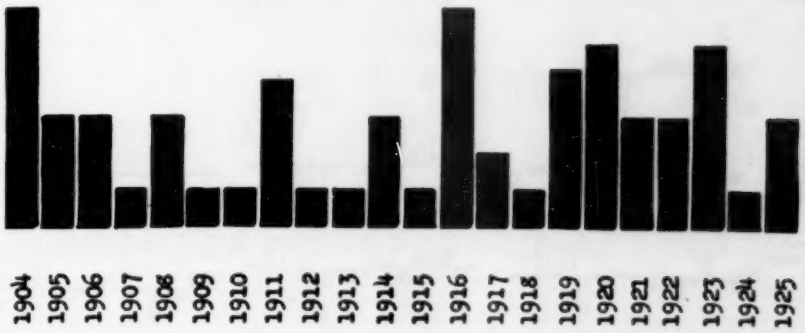

FIG. 6. Comparative severity of stem rust epidemics in the spring wheat area during the period 1904 to 1925, inclusive.

years are left out of consideration because it was thought that there was not enough difference between the amount of rust in these years and in the epidemic or non-epidemic years.

Stakman and Lambert (58) have already pointed out that the average mean monthly temperatures in Minnesota, North Dakota, and South Dakota during the three months considered were above normal for the epidemic years and below normal for the non-epidemic years.

They also showed that the amount of departure from normal seems to indicate a correlation between temperature in these three states and the occurrence of epidemics. The three coolest years were non-epidemic, and the five warmest years were epidemic or intermediate years. In these states, epidemics did not develop in seasons during which the average mean monthly temperatures in May, June, and July were below 61° F. Nor did

[21] This material was kindly placed at the writer's disposal by Dr. R. J. Haskell, Associate Pathologist, in charge of Plant Disease Survey, Bureau of Plant Industry, U. S. Department of Agriculture.

non-epidemic seasons occur when the average mean monthly temperatures were above 64° F. Both epidemic and non-epidemic years were included in seasons of medium average temperature (61°–64° F.). The comparative meteorological data upon which these conclusions were based are given in tables 10, 11, 12, and 13.

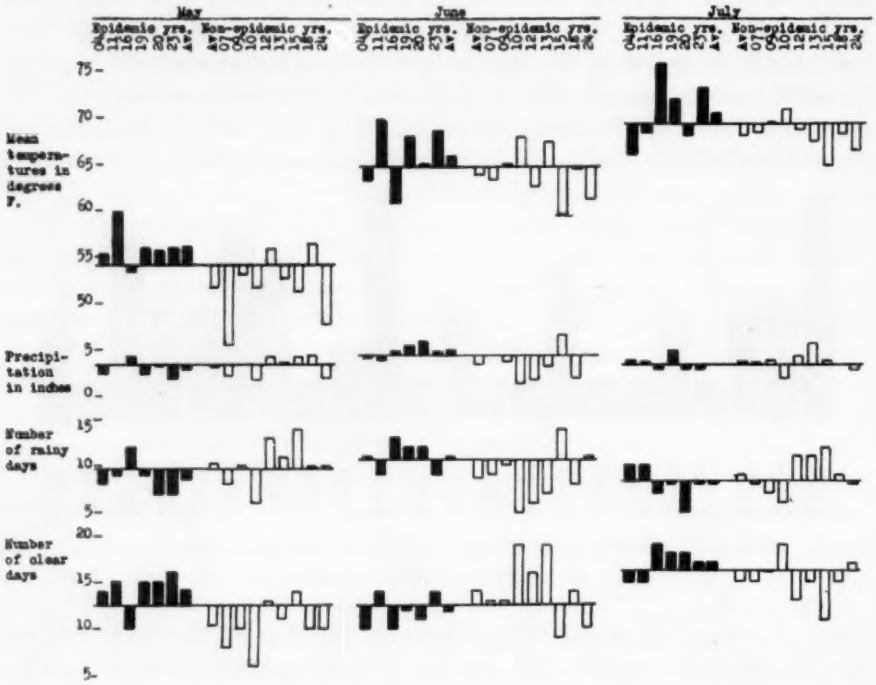

FIG. 7. Comparison of the departures from the normal Minnesota weather conditions which occurred during stem rust epidemic years and non-epidemic years in May, June, and July, from 1904 to 1925 inclusive.

At the suggestion of Dr. J. Arthur Harris,[22] an attempt was made to determine the mathematical significance of this apparent correlation between mean temperature and rust epidemics. The χ^2 test for goodness of fit was used.[23] The data are given in tables 14 and 15, and compared in table 15 with the distribution of years calculated on the basis of random sampling. The results indicate that deviations from the calculated distribution, as

[22] Professor of Botany, University of Minnesota.

[23] Following the usage in a recent paper in "Phytopathology" by C. H. Goulden, K. W. Neatby and J. N. Welch, the value of P was taken from Pearson's tables in the column under $n' = 5$. This takes into consideration the number of degrees of freedom as suggested by Fisher.

TABLE 10.—*Comparative meteorological data for May, June, and July, the critical months for the development of stem rust in Minnesota*

Year	May				June				July			
	Mean temperature, degrees F.	Av. precipitation in inches	No. rainy days	No. clear days	Mean temperature, degrees F.	Av. precipitation in inches	No. rainy days	No. clear days	Mean temperature, degrees F.	Av. precipitation in inches	No. rainy days	No. clear days
1904	55.4	2.43	8	14	63.2	4.26	11	10	66.0	3.96	10	15
1905	52.6	5.54	12	10	63.0	6.41	14	9	67.3	4.12	8	15
1906	53.7	5.58	14	9	63.7	4.55	12	10	68.3	2.93	8	17
1907	45.5	2.14	8	9	63.3	4.31	9	13	68.2	3.57	8	15
1908	53.9	6.31	12	11	62.5	6.35	12	10	69.4	3.21	8	18
1909	53.2	3.36	10	10	65.0	3.53	10	13	69.2	3.84	7	16
1910	51.6	1.58	6	16	67.8	1.39	5	19	70.6	1.94	6	19
1911	59.8	3.48	9	15	69.7	3.79	9	14	68.2	3.61	10	15
1912	55.9	4.13	13	10	62.5	1.66	6	16	68.5	4.30	11	13
1913	52.7	3.53	11	11	67.4	3.08	7	19	67.3	5.56	11	15
1914	57.6	2.89	9	14	64.6	8.34	15	10	72.4	2.48	6	18
1915	51.4	4.13	14	8	59.4	6.52	14	9	64.7	3.95	12	11
1916	53.5	4.27	12	10	60.8	4.93	13	10	75.5	2.85	7	19
1917	52.0	1.94	5	19	60.7	3.26	11	12	70.8	3.33	9	18
1918	56.4	4.39	10	10	64.4	1.99	8	14	68.0	3.35	9	15
1919	56.0	2.37	9	15	67.9	5.32	12	12	71.7	4.83	8	18
1920	55.6	3.14	7	15	64.9	5.95	12	11	67.9	2.88	5	18
1921	57.1	3.47	10	14	70.3	2.90	7	17	74.2	3.62	9	17
1922	60.2	3.07	10	10	66.4	3.00	9	14	67.3	2.26	8	14
1923	56.0	1.94	7	16	68.4	4.62	9	14	72.9	2.82	8	17
1924	47.7	1.85	10	12	61.1	4.27	11	10	66.4	2.77	8	17
1925	52.8	1.55	5	18	63.5	6.91	16	10	67.5	2.99	8	17
Averages	54.12	3.32	9.59	12.5	64.56	4.42	10.54	12.5	69.19	3.42	8.36	16.2

great or greater than those obtained, would be expected on the basis of random sampling only 15 times out of 100. In other words, the odds are 6 to 1 that the apparent correlation between warm growing seasons and destructive epidemics is not due to chance.

If a causal relationship is assumed, three noteworthy exceptions to the general rule must be explained; first, 1910 was a non-rust year in spite of the fact that a high temperature prevailed in June and July in Minnesota, North Dakota, and South Dakota. This was probably due to the fact that 1910 was the driest year in the 22 years considered. Second, a severe epidemic occurred in 1916 in spite of a cool May and June. This may be partially explained by the abnormally high temperature which prevailed in July, 1916. Third, an epidemic also developed in the moderately cool season of 1904. This seems to be a real exception to the rule, indicating that, in certain seasons, other factors may be favorable enough to induce an epidemic in cool seasons. (See figures 7, 8, and 9.)

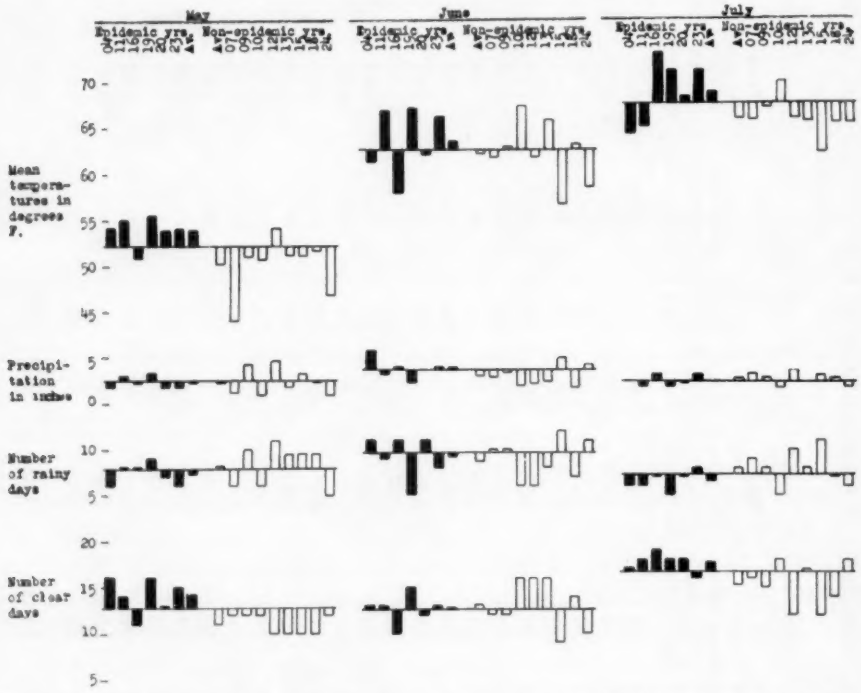

FIG. 8. Comparison of the departure from the normal North Dakota weather conditions which occurred during stem rust epidemic years and non-epidemic years in May, June, and July, from 1904 to 1925 inclusive.

TABLE 11.—*Comparative meteorological data for May, June, and July, the critical months for the development of stem rust in North Dakota*

Year	May				June				July			
	Mean temperature, degrees F.	Av. precipitation in inches	No. rainy days	No. clear days	Mean temperature, degrees F.	Av. precipitation in inches	No. rainy days	No. clear days	Mean temperature, degrees F.	Av. precipitation in inches	No. rainy days	No. clear days
1904	54.2	1.76	6	16	61.4	5.77	11	13	64.4	2.49	6	17
1905	50.1	3.05	8	12	59.7	4.52	12	10	65.6	3.90	8	17
1906	50.8	4.63	12	9	62.0	4.06	11	13	66.9	1.97	11	13
1907	44.0	1.11	6	12	61.9	2.85	10	12	65.8	3.14	9	16
1908	50.8	2.97	8	13	60.4	3.37	10	12	68.6	2.10	6	19
1909	51.0	4.29	10	12	62.9	3.21	10	12	67.1	2.89	8	15
1910	50.7	0.96	6	12	67.3	1.83	6	16	70.0	1.60	5	18
1911	55.0	2.88	8	14	66.9	3.12	9	13	65.1	1.82	6	18
1912	54.2	4.52	11	10	61.8	2.05	6	16	66.0	3.54	10	12
1913	51.2	1.68	9	10	65.8	2.35	8	16	65.6	2.30	8	17
1914	55.2	2.12	8	16	62.2	6.26	13	9	72.1	2.31	6	19
1915	51.1	3.16	9	10	56.7	5.00	12	9	62.3	3.01	11	12
1916	51.0	2.22	8	11	58.0	3.89	11	10	73.1	3.16	7	19
1917	51.2	0.30	2	20	59.7	2.09	8	13	70.9	1.66	7	17
1918	51.7	2.30	9	10	63.3	1.63	7	14	65.5	2.71	7	14
1919	55.5	3.25	9	16	67.2	2.31	5	15	71.2	1.81	5	18
1920	53.9	1.74	7	13	62.2	3.62	11	12	68.3	2.16	7	18
1921	52.8	2.46	9	13	68.2	3.51	9	14	71.4	3.07	7	17
1922	56.3	3.11	12	10	63.5	3.78	9	15	65.6	2.43	8	16
1923	54.1	1.77	6	15	66.1	3.82	8	13	71.2	3.14	8	16
1924	46.9	0.79	5	12	58.6	4.17	11	10	65.5	1.95	6	18
1925	53.6	1.44	4	17	61.5	6.07	14	11	66.7	1.34	6	18
Averages	52.05	2.38	7.81	12.86	62.6	3.60	9.59	12.63	67.67	2.47	7.36	16.54

TABLE 12.—*Comparative meteorological data for May, June, and July, the critical months for the development of stem rust in South Dakota*

Year	May				June				July			
	Mean temperature, degrees F.	Av. precipitation in inches	No. rainy days	No. clear days	Mean temperature, degrees F.	Av. precipitation in inches	No. rainy days	No. clear days	Mean temperature, degrees F.	Av. precipitation in inches	No. rainy days	No. clear days
1904	57.5	2.46	8	13	64.5	4.07	11	14	68.7	2.67	8	19
1905	53.0	5.84	12	11	64.4	5.78	12	10	68.5	3.63	8	16
1906	56.6	4.95	11	12	63.9	3.48	8	15	69.6	1.45	6	20
1907	48.9	3.83	8	12	64.2	3.90	9	15	69.9	4.35	11	16
1908	54.8	4.65	9	13	63.7	5.32	12	13	71.6	3.20	7	20
1909	54.8	4.85	10	11	66.9	4.10	11	13	71.0	3.07	8	18
1910	53.4	1.63	7	15	68.3	2.27	7	16	73.4	1.99	7	19
1911	60.3	1.70	6	15	73.4	1.85	6	17	71.0	2.08	7	17
1912	57.1	2.35	8	12	64.8	1.49	5	16	70.9	3.86	10	14
1913	54.4	3.48	11	9	69.6	2.50	7	16	71.1	2.43	14	16
1914	57.3	3.16	10	12	67.6	5.01	12	12	75.8	2.09	5	19
1915	52.0	3.64	12	7	60.3	5.34	13	10	65.3	5.89	13	11
1916	54.5	4.13	10	13	61.0	3.74	12	12	76.9	2.40	7	20
1917	51.8	3.16	8	14	62.7	2.08	7	15	74.3	1.47	5	21
1918	57.5	3.56	11	12	68.2	2.54	8	16	70.4	3.23	8	16
1919	56.2	2.79	8	17	68.7	3.13	8	15	74.9	2.85	6	19
1920	55.6	4.79	10	11	64.9	4.79	12	11	71.1	2.30	7	19
1921	56.5	3.21	11	10	72.5	2.10	6	18	75.0	3.41	8	18
1922	57.9	3.59	11	10	68.4	3.72	9	18	69.2	3.69	10	15
1923	55.4	2.40	9	12	67.0	4.53	11	13	74.6	3.45	9	15
1924	50.8	0.86	6	11	62.6	4.88	14	10	69.2	1.68	6	20
1925	56.4	1.52	5	15	65.5	5.66	12	13	71.5	1.74	6	19
Averages	55.12	3.16	9.13	12.13	66.05	3.74	9.63	14.0	71.54	2.86	8.0	17.59

Comparisons also were made to determine the relation of mean temperature in Texas, Oklahoma, Kansas, Nebraska, and Iowa, to the occurrence of epidemics in the spring wheat area. The results of these comparisons are given in figures 10 and 11, which are based on meteorological data given in tables 16 to 21 inclusive. It is evident that no striking correlation exists.

Number of clear days.—There seems to have been a tendency for epidemics to develop in years having the greatest number of clear days in the growing season. This may be attributed to a possible correlation between high temperatures and clear days. There is also a possibility that clear days are correlated with the formation of dew at night.

Rainfall and number of rainy days.—As indicated in figures 8, 9, and 10, there was no apparent correlation between the amount of precipitation and the development of epidemics with the possible exception of the effect of drought in 1910.

Dew.—The United States Weather Bureau does not record the formation of dew, nor has a systematic survey of the condition been included in

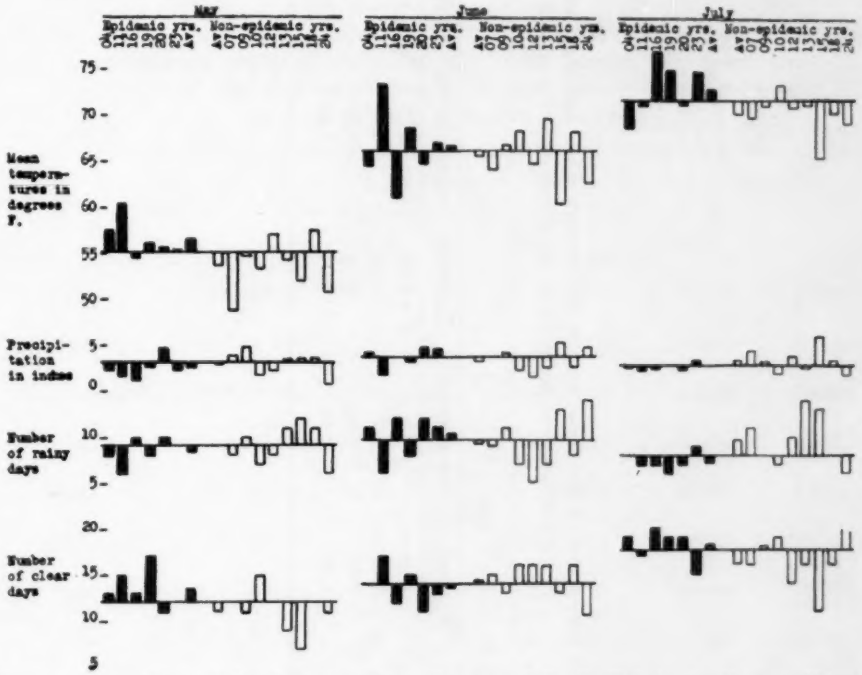

FIG. 9. Comparison of the departure from the normal South Dakota weather conditions which occurred during stem rust epidemic years in May, June, and July, from 1904 to 1925 inclusive.

TABLE 13.—*A comparison of the deviations, of the average mean monthly temperatures of the stem rust epidemic years with those of the non-epidemic years, from the average for the 22-year period 1904 to 1925, inclusive*

States	May		June		July		Average	
	Epidemic	Non-epidemic	Epidemic	Non-epidemic	Epidemic	Non-epidemic	Epidemic	Non-epidemic
Minnesota	+1.95	−2.3	+1.22	−0.73	+1.14	−1.32	+1.44	−1.45
North Dakota	+1.95	−1.9	+1.03	−0.3	+1.18	−1.75	+1.39	−1.32
South Dakota	+1.48	−1.49	+0.58	−0.39	+1.34	−1.35	+1.13	−1.08
Average	+1.79	−1.89	+0.94	−0.47	+1.22	−1.48	+1.32	−1.28

TABLE 14.—*Correlation between the average of the mean monthly temperatures for the growing season (May, June, and July) in the spring wheat area (Minnesota, North Dakota, and South Dakota) from 1904 to 1925 inclusive, and the development of stem rust epidemics in that area. Also the expected distribution calculated on the basis of random sampling*

Temperature (degrees Fahrenheit)	Epidemic	Uncertain	Non-Epidemic	
58–61		1	3	4
61–64	3	5	5	13
64–67	3	2		5
	6	8	8	22

TABLE 15.—*Classification of years during the period 1904 to 1925 inclusive on the basis of the occurrence of epidemics and the average of the mean monthly temperatures in May, June, and July, and the goodness of fit to the expected distribution calculated on the basis of random sampling*

Class	Number of years		O − C	$\frac{(O-C)^2}{C}$
	Observed (O)	Calculated (C)		
Epidemic ..... 58°–61° F.	0	$\frac{4\times6}{22}=1.0909$	−1.0909	1.0908
Uncertain ..... 58°–61° F.	1	$\frac{4\times8}{22}=1.4545$	−0.4545	0.1419
Non-epidemic ..... 58°–61° F.	3	$\frac{4\times8}{22}=1.4545$	1.5455	1.6421
Epidemic ..... 61°–64° F.	3	$\frac{13\times6}{22}=3.5455$	−0.5455	0.0839
Uncertain ..... 61°–64° F.	5	$\frac{13\times8}{22}=4.7273$	0.2727	0.0157
Non-epidemic ..... 61°–64° F.	5	$\frac{13\times8}{22}=4.7273$	0.2727	0.0157
Epidemic ..... 64°–67° F.	3	$\frac{5\times6}{22}=1.3636$	1.6364	1.9638
Uncertain ..... 64°–67° F.	2	$\frac{5\times8}{22}=1.8182$	0.1818	0.0181
Non-epidemic ..... 64°–67° F.	0	$\frac{5\times8}{22}=1.8182$	−1.8182	1.8181
Total	22	22.0000	Σ 7.8182	Σ 6.7901

$P = .149$ $\chi^2 = 6.7901$

TABLE 16.—*Comparative meteorological data for March, April, May, and June, the critical months for the development of stem rust in Texas*

Year	March				April				May				June			
	Mean temperature, degrees F.	Av. precipitation in inches	No. rainy days	No. clear days	Mean temperature, degrees F.	Av. precipitation in inches	No. rainy days	No. clear days	Mean temperature, degrees F.	Av. precipitation in inches	No. rainy days	No. clear days	Mean temperature, degrees F.	Av. precipitation in inches	No. rainy days	No. clear days
1904	64.8	1.05	2	15	66.3	2.98	6	14	72.5	4.56	6	17	79.9	4.28	6	15
1905	61.4	4.29	8	11	64.5	6.32	7	15	74.8	4.82	7	12	80.5	4.64	7	16
1906	54.0	1.72	5	14	66.3	2.67	6	11	73.3	2.98	6	14	80.6	2.71	6	18
1907	67.3	1.64	3	15	62.5	2.42	5	12	68.3	6.73	9	10	79.8	1.71	3	18
1908	64.3	1.65	4	13	67.0	5.08	9	11	73.5	5.69	5	14	81.1	2.48	4	15
1909	59.5	1.08	4	15	66.1	1.55	4	15	72.9	3.06	6	13	80.9	3.37	6	16
1910	64.4	1.55	3	19	65.9	2.59	5	17	72.4	3.91	6	13	80.6	1.90	4	18
1911	63.1	2.19	5	14	66.4	4.88	9	9	73.2	2.13	4	18	83.7	0.88	2	21
1912	53.1	2.75	7	9	65.8	2.87	6	12	74.5	2.28	5	18	77.4	3.71	5	16
1913	55.2	1.69	4	16	64.8	2.02	3	20	73.5	2.55	4	18	78.0	3.61	7	11
1914	56.3	2.45	5	16	64.8	4.28	6	12	71.3	7.68	11	9	81.1	1.47	3	19
1915	49.1	1.83	5	12	65.8	5.82	8	10	72.7	2.47	5	15	81.2	2.24	4	18
1916	63.7	0.64	1	22	64.2	3.44	5	14	74.4	3.80	5	18	81.7	2.17	4	18
1917	59.5	0.94	4	16	65.5	2.17	4	17	69.1	2.76	6	15	81.2	0.80	2	21
1918	62.8	1.35	3	15	65.1	3.99	6	14	74.6	2.40	4	14	83.3	2.45	5	17
1919	57.3	2.85	5	14	65.6	2.55	5	16	70.7	5.31	9	12	76.3	5.80	10	10
1920	57.3	1.33	3	16	65.0	1.05	3	19	74.3	5.11	7	12	78.1	3.58	7	16
1921	64.5	2.80	5	13	64.3	3.68	6	17	73.6	1.94	4	16	79.4	6.58	9	13
1922	57.7	3.69	5	16	67.6	6.26	7	10	75.0	4.46	8	14	79.5	3.55	6	15
1923	54.8	3.02	6	15	66.2	4.16	8	12	74.0	1.97	5	18	81.0	2.96	6	16
1924	53.6	2.26	6	14	65.6	2.83	4	13	70.0	4.35	7	13	82.1	2.12	4	21
1925	63.1	0.65	2	18	71.4	2.06	4	15	73.7	2.65	5	16	83.4	1.41	4	16
Averages ..	59.40	1.97	4.32	14.91	65.75	3.42	5.73	13.86	71.92	3.80	6.09	14.50	80.49	2.93	5.18	16.54

TABLE 17.—*Comparative meteorological data for May, June, and July, the critical months for the development of stem rust in Oklahoma*

Year	May				June				July			
	Mean temperature, degrees F.	Av. precipitation in inches	No. rainy days	No. clear days	Mean temperature, degrees F.	Av. precipitation in inches	No. rainy days	No. clear days	Mean temperature, degrees F.	Av. precipitation in inches	No. rainy days	No. clear days
1904	67.4	4.95	9	14	75.1	8.37	8	14	79.6	3.86	7	20
1905	69.4	7.51	11	13	78.5	1.88	5	18	77.7	5.50	9	16
1906	68.6	3.22	7	13	75.0	4.18	8	16	76.5	5.26	9	13
1907	61.9	5.02	10	13	75.1	5.34	8	16	80.7	2.13	4	22
1908	67.8	8.45	9	15	75.2	8.85	11	14	77.7	3.15	6	17
1909	67.1	5.49	6	17	76.5	3.45	9	15	83.7	2.13	4	21
1910	65.5	3.90	10	13	76.5	1.48	5	17	83.0	2.15	4	20
1911	71.3	2.61	6	18	84.0	1.12	3	23	80.7	5.34	10	13
1912	70.9	2.95	6	21	73.7	4.60	7	18	83.2	1.40	3	22
1913	70.4	3.50	6	17	76.0	2.62	7	12	83.8	2.38	4	20
1914	66.9	5.17	11	10	81.2	0.99	3	20	84.6	1.63	4	19
1915	65.8	6.01	9	15	74.2	7.12	11	12	78.5	2.92	6	19
1916	70.1	2.13	5	17	75.4	6.60	10	13	82.9	0.76	2	24
1917	62.5	2.32	6	13	76.8	2.09	4	21	83.3	2.57	6	19
1918	71.3	4.05	6	16	81.4	3.40	6	12	82.1	1.38	4	19
1919	66.0	4.61	11	9	74.5	4.29	10	11	81.7	1.75	4	22
1920	69.0	5.33	9	13	75.7	2.70	6	17	80.7	3.27	6	17
1921	70.0	2.04	6	14	76.2	8.05	14	8	81.2	2.49	5	19
1922	69.1	5.72	11	12	77.8	1.74	5	17	81.7	4.08	6	20
1923	67.0	6.63	10	13	77.2	5.01	11	16	83.2	1.10	3	20
1924	63.8	2.44	6	16	80.5	3.35	6	19	79.6	2.89	7	17
1925	68.0	2.23	5	17	82.5	2.13	5	19	83.7	3.95	9	14
Averages	67.71	4.37	7.95	14.50	77.22	4.06	7.36	15.81	81.35	2.82	5.55	18.77

our observations. Judging from personal experience, the writer is of the opinion that in the spring wheat area the formation of dew at night is the rule rather than the exception during June, July, and August. At St. Paul, Minn., heavy dew is usually present on grass at 10 p. m. and persists until 8 or 9 a. m. This would allow ample time for the penetration of the rust organism. The average relative humidity at 8 a. m. in July is higher in the Red River Valley in Minnesota than in any other part of the Mississippi Valley except the coast of the Gulf of Mexico. This high morning humidity is probably correlated with the occurrence of dew, and it may be more than a coincidence that grain usually suffers greater loss from stem rust in the Red River Valley, where the morning humidity is higher than in any other district in the Mississippi Valley.

During the rust survey in August, 1923, the writer, with J. J. Christensen, D. L. Bailey, and W. P. Fraser, found stem rust of 95 per cent severity

TABLE 18.—*Comparative meteorological data for May and June, the critical months for the development of stem rust in Kansas*

Year	May				June			
	Mean temperature, degrees F.	Av. precipitation in inches	No. rainy days	No. clear days	Mean temperature, degrees F.	Av. precipitation in inches	No. rainy days	No. clear days
1904	62.4	5.43	11	13	70.4	6.57	12	11
1905	63.1	4.42	10	13	75.5	3.75	7	15
1906	65.0	2.49	8	14	71.8	3.67	7	16
1907	58.3	2.37	8	13	72.0	4.83	10	15
1908	63.8	5.07	11	13	72.1	7.91	13	11
1909	62.2	3.66	8	14	73.1	5.46	12	11
1910	60.0	4.83	12	11	72.2	1.88	6	16
1911	66.7	2.66	8	14	80.5	0.64	3	21
1912	66.8	2.87	6	18	69.3	4.02	9	15
1913	66.7	2.90	7	16	74.2	2.45	7	13
1914	64.3	3.39	9	11	78.2	3.96	8	18
1915	60.3	6.85	12	14	69.2	6.46	13	9
1916	64.2	3.32	8	16	70.3	6.01	10	15
1917	57.5	3.50	9	12	72.8	2.11	5	21
1918	67.6	4.13	9	15	78.4	1.31	4	21
1919	61.3	2.97	9	11	72.3	4.36	10	14
1920	63.2	3.07	9	8	72.8	2.93	7	16
1921	65.5	2.61	6	14	74.4	5.00	11	12
1922	64.6	3.97	11	13	75.2	2.33	6	20
1923	61.3	5.75	12	12	73.0	6.10	11	13
1924	58.1	2.12	7	14	74.1	2.17	7	16
1925	62.9	2.16	7	15	77.6	4.03	8	18
Averages	62.99	3.66	8.95	13.4	73.6	3.99	8.45	15.3

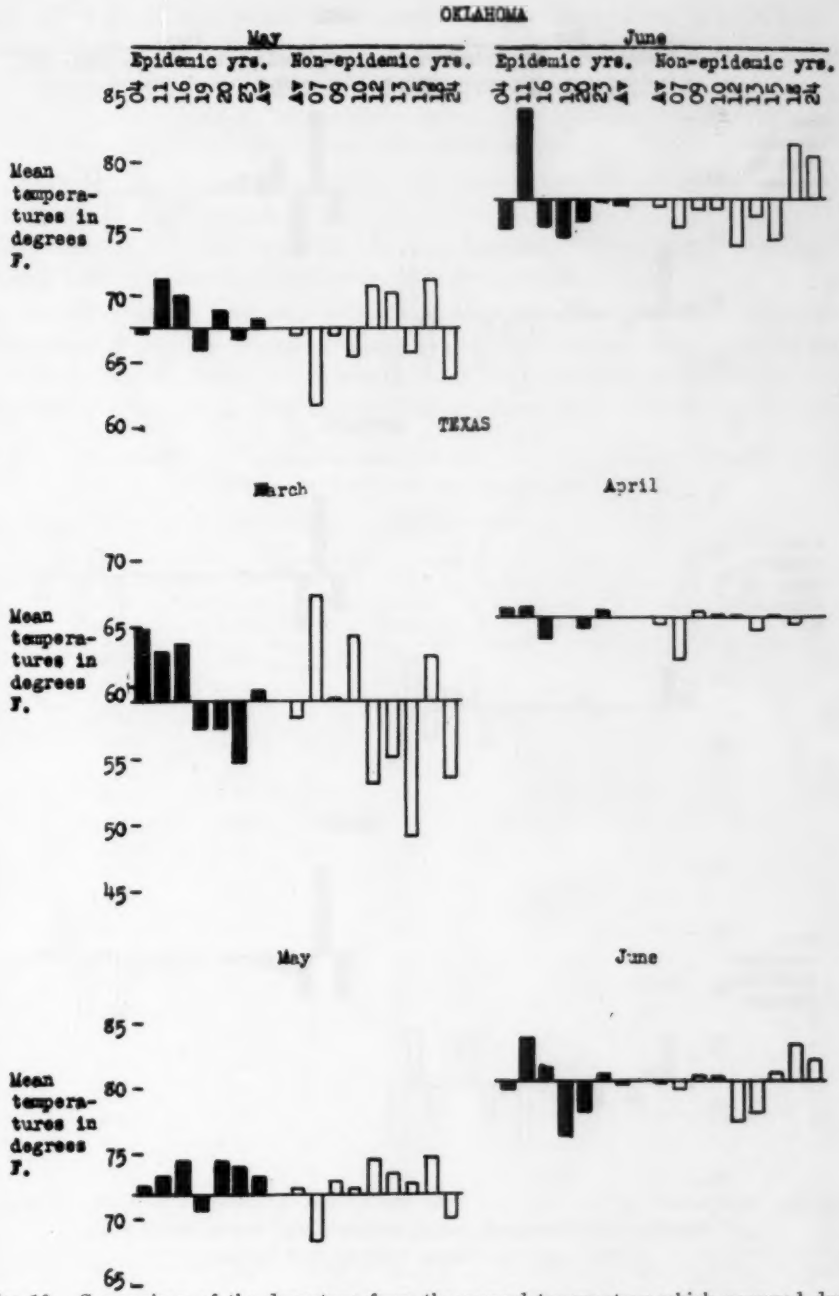

FIG. 10. Comparison of the departure from the normal temperature which occurred during the epidemic and non-epidemic years in Oklahoma in May and June, and in Texas in March, April, May and June, from 1904 to 1925 inclusive.

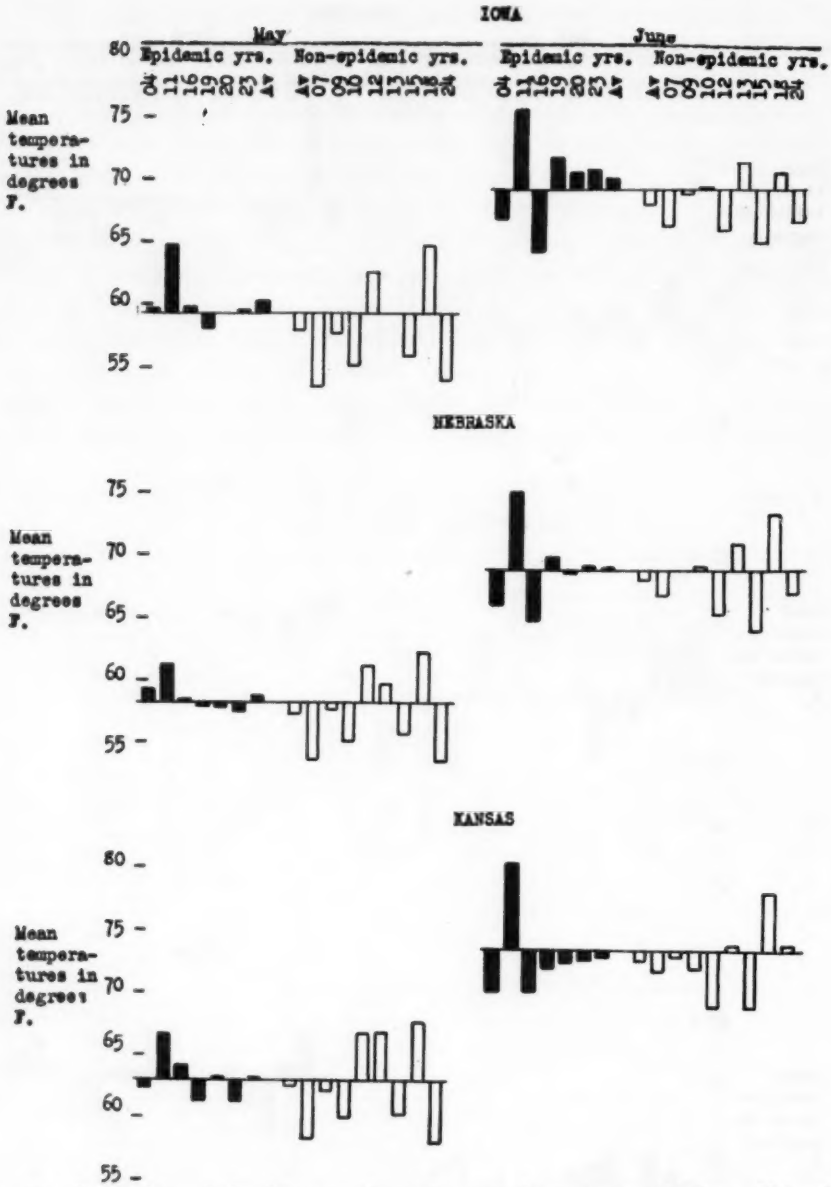

FIG. 11. Comparison of the departure from the normal temperature in Iowa, Nebraska and Kansas, which occurred during epidemic and non-epidemic years in May and June, from 1904 to 1925 inclusive.

in practically all late wheat fields near Morden, Man., Canada. This unusually severe epidemic developed in spite of the fact that there had been no rainfall in the vicinity of Morden for six weeks.

DISCUSSION AND CONCLUSIONS

Although the stem rusts of cereals are present every year throughout the Mississippi Valley, they do not develop uniformly in different parts of the valley nor in different seasons. In the Northern States barberries may become heavily infected, but they usually do not rust in Oklahoma or Texas. On the other hand, *Puccinia graminis tritici* and *P. graminis avenae* live throughout the winter in the uredinial stage in Texas and perhaps occasionally in Oklahoma, but there seems to be little or no overwintering in the Northern States. It is well known that the stem rusts of cereals are most

TABLE 19.—*Comparative meteorological data for May and June, the critical months for the development of stem rust in Missouri*

Year	May				June			
	Mean temperature, degrees F.	Av. precipitation in inches	No. rainy days	No. clear days	Mean temperature, degrees F.	Av. precipitation in inches	No. rainy days	No. clear days
1904	63.1	5.03	12	13	70.5	6.42	11	12
1905	64.9	4.87	10	12	75.2	3.09	7	15
1906	66.3	2.16	7	15	72.7	4.95	10	15
1907	59.5	5.56	10	14	71.2	5.84	11	14
1908	66.1	6.92	12	12	72.3	6.30	11	13
1909	63.3	5.34	9	15	73.9	5.21	11	11
1910	60.1	6.62	13	11	70.4	3.92	8	16
1911	68.8	1.55	5	19	78.9	1.78	6	18
1912	67.6	3.86	7	18	69.5	4.78	9	14
1913	65.8	3.05	8	16	75.4	2.57	6	18
1914	66.6	1.47	5	17	79.3	2.37	5	18
1915	63.7	7.86	12	12	70.8	6.51	12	11
1916	65.6	5.61	11	15	70.0	6.99	10	14
1917	58.7	4.33	10	15	71.0	3.78	8	19
1918	68.3	5.49	10	16	77.2	3.15	7	17
1919	62.0	5.80	13	10	75.0	5.59	11	14
1920	63.8	4.85	12	9	72.7	2.35	6	18
1921	66.4	3.69	7	17	76.6	5.71	12	12
1922	67.2	3.17	10	14	76.5	1.66	5	19
1923	62.7	4.59	12	11	73.5	5.48	11	14
1924	58.6	4.67	10	13	72.5	7.39	14	12
1925	61.2	2.14	7	14	76.5	6.10	9	15
Averages	6.41	4.48	9.63	14.0	73.71	4.63	9.09	14.95

prevalent in the spring wheat area, where destructive epidemics frequently develop. The observations of the writer and of several other investigators indicate that these regional and seasonal differences in the development of epidemics are due at least partly to certain specific differences in climate.

Stakman and his coworkers have shown that barberries do not rust in the south because, in that region, the teliospores are not viable in the spring. They either germinate in the winter or are killed by the high temperature of the summer months. To the writer the latter possibility seems stronger, because in all of his experiments teliospores which had been subjected to high temperatures failed to germinate in the spring.

Attempts have been made to determine the particular factors which from year to year establish the border line between regions in which stem rusts overwinter and regions in which they do not overwinter. The evidence at

TABLE 20.—*Comparative meteorological data for May and June, the critical months for the development of stem rust in Iowa*

Year	May				June			
	Mean temperature, degrees F.	Av. precipitation in inches	No. rainy days	No. clear days	Mean temperature, degrees F.	Av. precipitation in inches	No. rainy days	No. clear days
1904	59.6	3.78	8	13	67.1	3.45	7	13
1905	58.3	5.95	14	12	69.9	5.53	10	12
1906	60.8	3.54	11	13	67.9	3.92	8	15
1907	53.5	3.48	10	11	66.5	5.35	11	14
1908	59.4	8.34	15	9	67.1	5.66	13	12
1909	57.9	4.34	9	12	69.1	6.41	13	12
1910	55.4	3.41	10	15	69.5	1.99	7	18
1911	64.9	3.76	9	16	75.7	1.82	5	20
1912	62.7	3.33	10	14	66.2	2.74	7	15
1913	59.4	6.24	13	11	71.5	3.31	7	19
1914	62.2	3.31	10	14	72.2	5.57	13	12
1915	56.1	7.34	14	9	65.1	4.16	11	12
1916	59.9	4.93	12	13	64.5	3.71	10	13
1917	55.1	3.87	10	15	66.0	6.65	12	13
1918	64.9	6.87	13	13	70.8	5.29	11	16
1919	58.2	3.11	9	13	71.9	6.13	13	12
1920	59.4	3.26	8	14	70.7	3.56	9	16
1921	63.3	4.23	10	14	74.7	3.76	9	16
1922	63.4	3.53	12	13	72.2	1.82	6	19
1923	59.6	2.84	10	14	70.9	4.93	12	14
1924	54.1	1.71	9	13	66.8	8.10	14	11
1925	57.8	1.16	6	19	70.4	6.64	12	15
Averages	59.35	4.20	10.5	13.18	69.40	4.57	10	14.5

hand indicates that stem rust will overwinter readily only in regions in which alternate freezing and thawing are rare.

There are three possible ways for stem rusts to overwinter in the absence of their alternate host: urediniospores may remain viable throughout the winter and cause infection in the spring; dormant mycelium may persist in green leaves; or infection may take place repeatedly throughout the winter. Several workers have shown that, as a rule under field conditions, urediniospores lose their viability during periods of alternate freezing and thawing. Freezing temperatures do not seem to be so critical as alternate freezing and thawing, since in the Northern States urediniospores may remain viable throughout the winter months only to be killed in the spring at the time of alternate freezing and thawing. A reasonable explanation for this lies in the fact that urediniospores germinate at temperatures only

TABLE 21.—*Comparative meteorological data for May and June the critical months for the development of stem rust in Nebraska*

Year	May				June			
	Mean temperature, degrees F.	Av. precipitation in inches	No. rainy days	No. clear days	Mean temperature, degrees F.	Av. precipitation in inches	No. rainy days	No. clear days
1904	59.2	3.68	10	12	66.2	4.71	11	11
1905	56.2	5.73	12	9	68.4	5.04	11	10
1906	60.2	2.76	7	14	66.7	2.70	6	16
1907	53.7	2.88	8	11	67.0	4.03	9	15
1908	57.1	4.98	11	12	66.6	6.74	13	11
1909	57.6	3.23	9	12	69.0	4.26	10	12
1910	55.2	2.80	9	13	69.4	2.65	7	15
1911	61.2	2.27	6	14	75.2	1.76	4	20
1912	61.2	1.80	6	15	65.6	2.31	7	15
1913	59.8	3.60	9	13	71.1	2.73	7	18
1914	60.6	2.67	8	14	72.3	4.66	9	16
1915	55.8	5.25	12	12	64.2	5.81	13	10
1916	58.5	3.51	9	15	65.0	3.38	9	15
1917	53.2	4.85	11	12	67.0	3.24	8	19
1918	62.3	3.97	9	14	73.5	1.93	6	21
1919	57.9	2.54	7	16	70.0	4.94	10	16
1920	57.9	3.55	10	10	68.9	2.95	9	15
1921	60.7	3.62	9	12	73.0	2.35	7	17
1922	60.3	2.77	8	13	72.2	2.41	6	21
1923	57.5	4.99	11	13	69.3	4.70	10	13
1924	53.6	1.90	7	13	67.1	4.27	11	14
1925	58.7	2.06	6	16	70.9	4.46	11	15
Averages	58.11	3.43	8.82	12.95	69.02	3.54	8.82	15.22

slightly above freezing, while the minimum temperature for the penetration of the host is several degrees higher. Presumably the urediniospores germinate prematurely at temperatures too low for infection to take place. Peltier and others have shown that at low temperatures stem rust mycelium may remain dormant in wheat leaves for several weeks. North of Oklahoma, however, the chances for mycelium to live through the winter seem slight, because infection usually does not occur under field conditions later than October; in the cases studied the mycelium has always died in midwinter. In the district near Dallas, Texas, where detailed observations were made by Frolik, Butler, and the writer, in the winter of 1923–24, stem rust apparently was killed in January and February; while in the same winter, at San Antonio, Texas, the rust propagated itself throughout the winter. There were two striking differences between the weather conditions in these areas. In the vicinity of San Antonio, during the months of December, January, and February in that winter, there were four periods in which the mean temperatures ranged from 18° C. to 25° C. (65° F. to 78° F.), accompanied by sufficient rainfall for uredinial reproduction. At Dallas, on the other hand, such favorable conditions prevailed only once. Moreover, there was alternate freezing and thawing only four times at San Antonio, as contrasted with twenty times in the Dallas district. Here, alternate freezing and thawing seemed to check rust development by killing the host leaves bearing the old pustules as well as by causing viable urediniospores to germinate prematurely.

Of course, climate also affects the regional development of stem rust indirectly by determining the geographic limits of cereal crops. For example, *Puccinia graminis avenae* can not overwinter on grain north of Oklahoma because winter oats is not grown in the Northern States. Likewise, *Puccinia graminis secalis* can not overwinter in any great quantity south of Kansas because there is practically no rye grown in the south.

These in general appear to be the ways in which climate affects regional differences in the development of stem rusts. Another question of general interest is to what extent are seasonal fluctuations in rust development due to weather conditions?

This leads naturally to the question, can the development of destructive epidemics in the spring wheat area be correlated with certain weather conditions? There are two sources of inoculum which are known to contribute to the development of these epidemics: urediniospores or aeciospores which have been blown into the area from a distance, and aeciospores from barberries within the area. Assuming that these are the principal sources, it is evident that the weather might affect the development of epidemics in several ways: winter and spring weather conditions may affect overwinter-

ing or the accumulation of urediniospores in the south; the direction and velocity of winds may determine whether inoculum is blown into the spring wheat area; weather conditions in early spring may affect the severity and time of barberry infection; and, within the spring wheat area, weather conditions during the growing season may affect the rate of accumulation of inoculum, the rate of maturity of the host, and the amount of excessive transpiration caused by stem rust infection.

In southern Texas stem rust apparently overwinters more readily in some years than in others. But the problem of correlating this seasonal fluctuation with weather conditions is not a simple one. In the first place, it is difficult to determine the relative amount of overwintering from year to year because even in favorable years stem rust overwinters in only a few fields in a hundred. The amount of general primary infection in the spring can not be depended upon as an index to overwintering, as there is always the possibility of inoculum having been blown in from Mexico. The problem is complicated further by the fact that overwintering is so largely dependent on fall infection, which in turn is determined by factors such as oversummering of urediniospores, possible migration of inoculum from north to south in the fall, date of sowing of grain, and the time of emergence of volunteer grain in the fall. Because of the meagerness of our knowledge of these factors, no attempt has been made to correlate seasonal differences in overwintering with winter weather conditions.

In Texas stem rust accumulates most rapidly in April and May, while farther north in Oklahoma, Kansas, Missouri, Iowa, and Nebraska it develops principally in May and June. Temperature might be assumed to affect the rate of accumulation of inoculum in these states and thus indirectly affect the development of epidemics farther north. However, there is no indication of a correlation between mean monthly temperatures during these critical months in the Southern States and epidemics in the spring wheat area.

The diffused nature of primary infection in the spring wheat area suggests a distant source of inoculum. It has been shown by actual observation that spores are disseminated directly for several miles from barberries, and there is circumstantial evidence that spores are disseminated many miles from local epidemics near barberries. Stakman and his coworkers have shown that viable urediniospores are present in the air at high altitudes over heavily rusted fields. Observations on the movement of dust indicate that the wind is capable of carrying these spores long distances. Steady south winds frequently blow with sufficient velocity to carry spores from southern Texas to the spring wheat area in a few days. It is evident from the daily weather maps that each year for the past 25 years such air cur-

rents have taken a northerly course for one or more days in the last two weeks in May and the first two weeks in June. As inoculum is most abundant in the south during late May and early June, and general primary infection in the north usually begins at about that time, it seems at least probable that there is some correlation between these conditions. So far as the writer could determine, however, strong south winds were not consistently more prevalent during this period in epidemic years than in non-epidemic years.

Clearly, then, there is no outstanding evidence of a correlation between the development of epidemics in the spring wheat area and weather conditions south of that area. Attempts also have been made to determine whether certain weather conditions within the spring wheat area are associated with the development of epidemics.

The relation of meteorological conditions to the development of epidemics of stem rust in the spring wheat area is complex, even when conditions outside the area are left out of consideration. The growth and maturity of the cereal hosts must be considered as well as all of the phases of the life cycle of the rust. Each of these phases involves the production, liberation, dissemination, and germination of spores, and the phenomenon of infection. Many of the factors which favor or retard these phenomena have been determined by controlled experiments. But it is difficult to apply the results of these controlled experiments toward the solution of field problems because so many interrelated factors are involved. The historical method, by which weather conditions during epidemic years are contrasted with conditions during years comparatively free from rust, seems to be the most promising. This method is somewhat empirical, but it has the advantage of considering the effects of weather on the growth of wheat and on practically all phases in the life cycle of the rust, without leading to a confusing mass of detail.

It is generally agreed that weather conditions have the greatest opportunity to affect rust development in the months of April, May, June, July, and August. With the possible exception of the accumulation of soil moisture, it does not seem likely that winter weather conditions materially affect epidemics, inasmuch as teliospores appear to have a true rest period and are dormant in the winter. Spring wheat usually is sown during the last two weeks of April. Teliospores germinate in the latter part of April and barberries usually become infected early in May. Thus the weather in April and May might be expected to affect the time and degree of infection on barberries and to retard or accelerate the seedling growth of wheat. In June and July, rust spreads from barberries, and multiplies in the uredinial stage from the general primary infection; spring wheat also makes

its principal growth during this period. Stem rust causes the greatest damage to wheat during the period between flowering and the hard-dough stage. This usually is late in July or early in August.

Freeman and Johnson called attention to the fact that the epidemic of 1904 developed in a moderately cool season and that the month of July was unusually cool. It was their opinion "that the unusually low temperature over this region was a very important factor, if not the determining factor, for the prevalence of rust in 1904." They pointed out that the cool season delayed the development of the host and that this delay was especially detrimental during the period between heading and maturity, when the rust was most prevalent. In 1916 there was another terrific epidemic. However, in July of that year—roughly the period between heading and ripening of wheat—the mean temperature was extremely high. Because of events of this kind two schools of thought have arisen. One group of observers are inclined to the opinion that cool seasons favor epidemics by delaying the crop to a greater extent than the rust. The other group maintains that epidemics are more likely to develop in warm seasons because the development of the rust is accelerated by warm weather to a greater extent than is the development of wheat, and because excessive transpiration due to rust injury is greater at higher temperatures. Stakman and the writer have shown that, as a rule, warm growing seasons in the spring wheat area have been associated with stem rust epidemics during the period from 1904 to 1925 inclusive. It was further pointed out that there were no destructive epidemics in years in which the average temperature for the growing season was below 61° F.; nor did non-epidemic seasons occur when the average temperature was above 64° F. More detailed evidence along the same line has been presented in this paper. It is undoubtedly true that, during this 22-year period, the majority of the epidemic years were warmer than normal and the majority of the non-epidemic years were cooler than normal. This strongly suggests a causal relationship between warm growing seasons and epidemics. But it should be clearly understood that there is one chance in six that this correlation between warm growing seasons and epidemics is fortuitous.

When such conditions as the mean monthly precipitation during the growing season, the number of rainy days, the number of cloudy days, or the number of clear days during epidemic years are compared with those in non-epidemic years, there is even less indication of a correlation than in the case of temperature.

In conclusion, then, there is evidence that weather conditions are partly responsible for regional differences in the development of stem rust and for the irregular recurrence of destructive epidemics. Barberries do not

become infected in the south in all probability because teliospores are killed by the heat of the summer months. Alternate freezing and thawing seems to be the critical factor which determines the borderline between regions in which there is abundant overwintering in the uredinial stage and regions where stem rust does not overwinter extensively. In the spring wheat area there seems to be a tendency for epidemics to develop in warm growing seasons. Otherwise there is little or no evidence of a correlation between seasonal weather conditions and stem rust epidemics. There apparently are no other specific meteorological conditions or sets of conditions which usually accompany severe epidemics in the spring wheat area, and there is apparently no evidence of an association between weather conditions outside the spring wheat area and epidemics within the area. The problem is complicated by the presence of more than one possible source of inoculum and by the fact that conditions which favor the pathogene also may favor the development of the host. The development of severe epidemics on oats in years when stem rust is scarce on wheat, and *vice versa*, further illustrates the complexity of the problem. Similarly, the predominance of different physiologic forms of *P. graminis tritici* in different years must be considered. With so many interrelated factors involved, each epidemic appears to be a law unto itself. More precise information is needed, but the observer can not be cautioned too strongly against mistaking coincidences for causal relations.

SUMMARY

1. The weather affects the development of all phases in the life cycle of the stem rust organism.

2. Teliospores apparently lose their viability if kept for several months at high temperatures. It is suggested that this may explain the absence of rust on barberries in the Southern States.

3. Such factors as alternate freezing and thawing, alternate wetting and drying, light, and chemical stimuli did not have a measurable effect on the rest period of teliospores. Time seems to be the most important factor.

4. For the past five years at St. Paul, Minnesota, teliospores were shown to be viable several weeks before barberry leaves appeared in the spring.

5. After teliospores are matured, different lots of spore material, and even spores from different sori on the same straw, may require different lengths of time for germination. This probably facilitates barberry infection by insuring the germination of teliospores in several rainy periods.

6. Teliospores germinate in a wide range of H-ion concentrations, and apparently are not affected by light.

7. In nature teliospores usually lose their viability a few months after they mature but, if kept in cold storage, they may be preserved for nearly a year.

8. Field observations indicate that almost invariably teliospores can be found within a few rods of heavily rusted barberries.

9. The optimum temperature for the infection of *Berberis vulgaris* by *Puccinia graminis secalis* is 17°–18° C. Infection was sparing at 22°–23° C. and practically absent at 26° C.

10. Penetration of barberry leaves seems to be favored by low light intensity, while the development of aecial infection, after penetration, appeared to be favored by intense light.

11. There is some indication of a correlation between the mean temperature and rainfall in April and the earliness and severity of barberry infection in Minnesota.

12. Overwintering of urediniospores seems to be limited to seasons and regions in which temperature and rainfall favor the development of the uredinial stage at frequent intervals throughout the winter. Periods of alternate freezing and thawing are apparently a limiting factor.

13. In southern Texas weather conditions in summer seem to be more important as a limiting factor to the persistence of the uredinial stage than winter weather conditions.

14. In 1926 the predominance of stem rust on oats in northern Texas over that on wheat appeared to be associated with weather conditions during the previous year which were favorable for the development and persistence of volunteer oats.

15. The extent of the observable dissemination of urediniospores depends upon the amount of inoculum present. The rust from a single pustule usually develops through several generations before sufficient inoculum has accumulated to cause a noticeable infection at a distance of several rods.

16. When rust becomes plentiful throughout one or more fields of grain, it may spread, in observable amounts, for several miles to surrounding fields. There is circumstantial evidence that rust may be blown several hundred miles from a severely infected area.

17. Southerly winds have been shown to sweep up the Mississippi Valley, at the time stem rust is most plentiful in the south, with sufficient velocity to carry spores from Texas to the spring wheat area in less than three days. There is circumstantial evidence that conditions of this kind occurred from one to several times during the last ten days in May and the first ten days in June in every year for the past 25 years. But there is no apparent correlation between the prevalence of these winds and the occurrence of epidemics in the spring wheat area.

18. A comparison of the mean temperature in May, June, and July in epidemic years with that in non-epidemic years indicates that there is a correlation between warm growing seasons and destructive epidemics in the spring wheat area.

19. Differences in the total precipitation or the number of rainy days during May, June, and July do not seem to be associated with the development of epidemics. Field observations indicate that severe epidemics sometimes develop in parts of the Red River Valley in which rainfall is totally absent. It is suggested that heavy dew may account for this condition.

20. No evidence was obtained of any specific meteorological condition or set of conditions that always accompanies epidemics.

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A NEW VIRUS DISEASE EPIDEMIC ON ONIONS

I. E. Melhus, C. S. Reddy, W. J. Henderson and Edgar Vestal

This paper is a preliminary report of investigations of a new onion disease which occurred in epidemic form in the Pleasant Valley onion district of Iowa in May, 1928.

The sudden development of the disease in epidemic form on one of our most intensive crops, coupled with its unknown nature, warrants directing the attention of all pathologists to its presence, appearance, and destructiveness. Although comparatively little is known as yet about this disease, it is already reasonably certain that an additional cultural practice will be necessary in order to continue growing onions in areas where this disease becomes established. In all probability it will be necessary to index for the presence of the disease in mother bulbs and onion sets produced in diseased areas.

This virus disease did not come into existence this year. It was observed in June, 1927, in the same district, and specimens were collected. At that time the disease was not common and the growers considered it probable that the few affected plants either had been damaged by a hail storm or merely lacked sufficient vitality to produce normal growth. Isolations were made from a collection made at that time with only negative results, and results of inoculations with the juice from crushed tissue on other onion tops also were negative.

The seriousness of the disease was first recognized in May, 1928, when 95 per cent of the mother bulbs planted to produce seed were found to be diseased in some fields. A little later the disease was observed to be prevalent in the principal acreage planted with onion sets. Onions are grown from sets as well as seed for commercial purposes in this district. Here the infection ranged from 15 to 50 per cent, although in a few fields as many as 95 per cent of the plants were infected. The financial loss cannot be determined accurately, but 25 per cent is a conservative estimate of the loss induced this season in the Pleasant Valley section.

Later in the season commercial onions grown from seed became diseased, but the plants showed the symptoms at about the same stage of growth as those grown from sets. Where seed was planted thickly to produce sets, the disease appeared later in the growing season, when the plants had developed five leaves. The symptoms were less evident than on plants grown from mother bulbs and sets.

Fields in outlying sections where the growers used their own sets were much freer from this disease. In fact two fields were located where neither the seed crop nor the commercial onion crop grown from sets showed a single infected onion. In other fields in outlying sections where the sets had been purchased from growers in the Valley the percentage of infection was as high as observed in the more intensive onion district.

SYMPTOMS AND COMMON NAME

The symptoms of this new virus disease are very striking and conspicuous. In advanced cases the plants are severely stunted and yellow, the lopped-over leaves superficially suggesting a wilt. In the field on

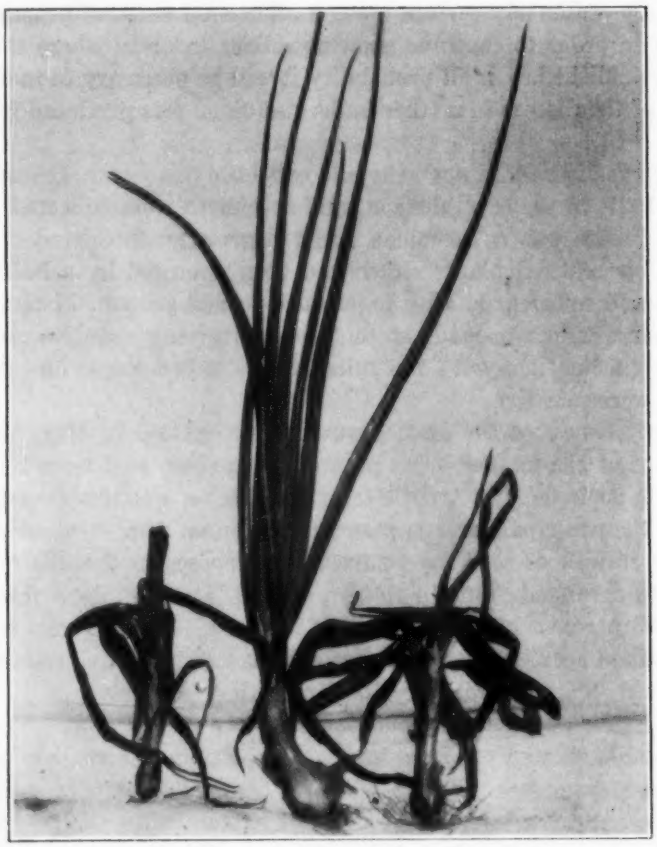

FIG. 1. Yellow dwarf disease on two Yellow Bottleneck onions and a healthy onion of the same variety between them, grown from sets at Pleasant Valley, Iowa, 1928.

plants from sets the symptoms usually first appear on the fifth leaf, but this may be owing to masking on account of temperature, because when sets are planted later than normally in warm soils in the greenhouse the disease symptoms often occur on the earlier formed leaves.

On the leaves are yellow streaks which sometimes extend the full length of the leaf. In other cases the yellow streaks are much shorter. Such leaves as a rule are chlorotic throughout, are crinkled and flat, lose their turgidity and lop over with the tips touching the ground. In other cases only a part of the leaf may show symptoms. The flower stalk does not react to the disease like the leaves, but remains turgid and round although it is often chlorotic, bent and twisted, and from 6 to 10 inches shorter than normal. Marked stunting occurs on all diseased plants, but particularly on those grown from sets and mother bulbs. The stunting is least on the onion sets grown from seed. As stunting and yellowing are two of the conspicuous symptoms, the common name suggested for this disease is "yellow dwarf of onions" (Fig. 1).

SPREAD OF THE DISEASE

From numerous observations and experiments it is known that the disease is carried in the onion sets and mother bulbs, but not in the seed. Seed grown in the Pleasant Valley district in 1927 and planted in three places in Iowa, one in Wisconsin, and one in Minnesota, in 1928, produced crops free from the disease. On the other hand, wherever onion sets were distributed in a like manner, the disease occurred, showing that the vegetative stage of the host may carry the disease over winter. In greenhouse experiments at Ames, Iowa, the disease developed whenever sets or mother bulbs grown in the Pleasant Valley district were used. It was at first thought that no symptoms appeared during the year that infection occurred; but later in the season the disease occurred on onions grown from seed. Since the disease is not carried on the seed, it must have been transmitted to the young plants during the current year.

CAUSE OF THE DISEASE

The character of the disease symptoms and the repeated failures to find an organism consistently associated with the disease suggested a virus.

The following experiments tend to substantiate this supposition. Onion plants infected with the yellow dwarf disease were crushed by means of a small food chopper. A small quantity of distilled water was added to this crushed material and the mixture ground in a mortar. After stirring for a few minutes, the diseased juice was filtered and the filtrate used in experiments.

The onion sets used in the six inoculation trials recorded were obtained from William Hartz, of Pleasant Valley, Iowa. In his field planted from this lot of sets about 10 per cent of the plants were infected. It was the healthiest lot of sets of the Yellow Bottleneck variety available when the inoculations were undertaken. This sort is one that has been improved in this district and the one preferred by all the growers. The sets were inoculated by injecting into them about 1/10 cc. of the juice from diseased onions. Each time that 100 onion sets were inoculated and planted, 100 uninoculated sets from the same lot were planted as checks. The results of these inoculation experiments are recorded in table 1.

TABLE 1.—*Inoculation experiments on units of 100 Yellow Bottleneck sets in which infection was determined by subsequent growth from the sets growing in the field, Pleasant Valley, Iowa, 1928*

Trial no.	Date planted	No. days between planting and final reading	Inoculated sets; no. diseased	Check sets; no. diseased
1	June 22	24	59	16
2	" 30	17	22	7
3	" 30	17	20	7
4	" 30	18	30	6
5	" 30	18	29	6
6	July 6	12	26	3

Table 1 shows that the highest percentage of infection occurred in trial No. 1; the checks showed 16 per cent and the inoculated lot 59 per cent. Probably the method of inoculation was the most important variable in these trials. In the first trial the inoculum was injected deeper into the bulbs than in the other five trials. Without exception a higher percentage of diseased plants developed in the inoculated sets than in the uninoculated. The average was 31 per cent infected plants in the 600 inoculated sets and 7.5 per cent in the checks. These results tend to support the supposition that the cause of the disease is a virus and that it can be transmitted artificially by injections of juice from diseased onion plants into other onion sets. More than four times as many yellow dwarf plants developed from the 600 onion sets inoculated than from 600 similar onion sets not inoculated. The symptoms of the yellow dwarf disease manifested themselves in 9–12 days when the plants were growing rapidly. If the plants are not growing rapidly it may require a longer time, and if the growth is very slow no signs of the disease will develop.

Although the experimental work has not progressed far enough to justify definite statements relative to control of this disease, nevertheless these suggestions may be of value to other workers. The most practical way of combatting this disease is to use sets known to be disease free. However, when it is necessary to obtain seed stocks from an infested district, the distinctiveness of the symptoms coupled with the promptness with which they appear under good growing conditions suggests that stocks of sets and mother bulbs may be readily indexed before planting for the presence or absence of the disease.

IOWA AGRICULTURAL EXPERIMENT STATION,
AMES, IOWA.

ABSTRACTS OF PAPERS PRESENTED AT THE TWENTIETH ANNUAL MEETING OF THE AMERICAN PHYTOPATHOLOGICAL SOCIETY, NEW YORK, N. Y., DECEMBER 28, 1928, TO JANUARY 1, 1929

Relation of the removal of smut balls to the control of stinking smut in winter wheat. R. S. KIRBY.

Three years' tests have shown that when winter wheat containing 1–10 per cent of smut balls is treated with copper carbonate dust and is planted by grain drills, approximately an equal percentage of smut results in the succeeding crop. When the same wheat is planted by hand without rupturing the smut balls, practically no stinking smut occurs in the succeeding crop.

This led to a study of the efficiency of cleaning machinery in removing smut balls. A combination cleaning and treating machine of the screen-and-air-draft type, with a capacity of 60–75 bushels of wheat an hour, removed 91.5 per cent of the smut balls. A cockle disc cleaner removed 83.3 per cent while cleaning 100–150 bushels an hour. A receiving separator of the screen-and-strong-air-draft type, cleaning 100–150 bushels an hour, removed 100 per cent of balls when less than 3 per cent was present, but let a few through at over 3 per cent. Running the seed through both the disc machine and receiving separator removed all smut balls in every lot containing less than 10 per cent. These figures are based on the treatment of over 31,000 bushels of wheat with these machines.

The influence of environment during maturation upon predisposition to seedling blight in wheat and corn strains. JAMES G. DICKSON, P. E. HOPPE, J. R. HOLBERT, and GEORGE JANSSEN.

The past three years' tests have shown a marked relation between the environment during the period of maturation and the subsequent growth responses of the seedling as well as the complete seasonal development and yield of the crop. High-yielding, resistant strains of spring wheat became susceptible and poor producers when the seed was grown one season under the hot, midsummer conditions of central Illinois, whereas the seed of the same strains matured at Madison, Wis., resulted in resistant plants and yields characteristic of the strains.

Similar results have been obtained in late-maturing inbred lines of corn when grown at Madison under unfavorable fall conditions. This so-called immature corn even in highly resistant inbred lines has been completely susceptible to seedling blight and produces plants and ears of markedly inferior quality, unlike those from the original line or from plants from well-matured ears of the same line. This does not seem to be a disturbance of the genetic composition of the line but rather the expression of the characters. There is little difference in endosperm composition, but marked changes in the embryo. This influence of the maturation environment is of special importance in comparing strains or varieties matured under different conditions. (Cooperative investigations between the Wisconsin Agricultural Experiment Station, Office of Cereal Crops and Diseases, Bureau of Plant Industry, United States Department of Agriculture, and Funk Brothers Seed Company.)

Inheritance of resistance to seedling blight of corn caused by Gibberella saubinetii. P. E. HOPPE.

In studying mode of inheritance of resistance to seedling blight of corn caused by *Gibberella saubinetii*, selfed strains of corn have exhibited wide range of relative resis-

tance when inoculated and grown at 16° C. Their consistent behavior at this temperature indicates high degree of homozygosity for the genetic factors involved in resistance.

F_1 hybrids from a resistant × susceptible cross were as resistant as the resistant parent. Hybrid vigor does not necessarily mask susceptibility, as shown by a susceptible × susceptible cross which was as susceptible as either parent.

Analyses of 27 F_2 families gave evidence of transgressive segregation, as families were isolated more susceptible and more resistant than parent strains. One F_2 family, practically immune, maintained its high degree of resistance in the F_3, while results in other families indicated that the F_2 families had been very heterozygous.

Environmental factors as well as degree of maturity of seed greatly affect expression of resistance. It is necessary therefore to test all genetic generations simultaneously and under the same environment before one can expect an accurate analysis of the manner of inheritance of resistance to this disease. Material is available for such a study to be conducted during the winter of 1928–29. (Cooperative investigations between Wisconsin Agricultural Experiment Station and Office of Cereal Crops and Diseases, Bureau of Plant Industry, United States Department of Agriculture.)

Susceptibility of barley varieties to Fusarial head blight in Minnesota. J. J. CHRISTENSEN, H. A. RODENHISER, and CHIH TU.

Scab was unusually prevalent on barley in southern Minnesota in 1928. At University Farm, 132 varieties and selections, grown in duplicate series, were subjected to an artificial epidemic produced by several species of *Fusarium*. Some varieties were extremely susceptible, some highly resistant, still others intermediate. The percentage of infected heads ranged from a trace to 100 per cent. A correlation coefficient of $+.50 \pm .04$ was obtained between the behavior in the two series. The heads of some of the most susceptible varieties were completely ruined, *viz.*: Meloy, C. I. 1176; Club Mariout, C. I. 261; Flynn, C. I. 1311; and many others. Some of the resistant varieties grown in Minnesota are: Improved Manchuria, Minn. 184 (17 per cent); Svansota, Minn. 440 (7 per cent); Peatland, Minn. 452 (4 per cent). In Glabron, Minn. 445, and Velvet, Minn. 447, two recently developed smooth-awned varieties, 49 and 68 per cent of the heads respectively were infected. Fusarial head blight may become an important factor in barley production if susceptible varieties are developed and supplant the more resistant ones. There is no apparent correlation between varietal resistance to scab and to spot blotch.

Ethyl mercury chloride as a seed grain disinfectant. W. H. TISDALE and W. N. CANNON.

The E. I. duPont de Nemours and Company has investigated many materials in an effort to develop a dust with a greater range of effectiveness than is possessed by the copper, formaldehyde, and certain of the mercury dusts on the market. Chemists of the company suggested ethyl mercury chloride as a possibility. In toxicity tests, this product proved highly effective against certain bacteria and fungi. Different dust combinations, each including a number of strengths of the toxin ranging from 0.5 to 4 per cent, were prepared and tested on infested seeds. They proved highly effective in the control of the diseases but in some cases the seeds were injured. Combinations and strengths have since been prepared which cause no injury to the seeds of the small grains, but give excellent disease control. Very satisfactory results have been obtained in the control of bunt of wheat, covered smut and the stripe of barley, loose smut of Tennessee Winter barley, the smuts of oats, and covered kernel smut of sorghum. For control of these diseases a thorough dusting of the seed with a 1.5 per cent product has been found sufficient. Tests are under way on other seeds. (Bayer-Semesan Company.)

Experiments with liquid and dust seed disinfectants for controlling covered smut of barley and stinking smut of wheat, 1926–1928. R. W. LEUKEL.

Covered smut of barley was eliminated without seed injury by soaking seed one hour in 0.5 per cent solution of Uspulun, Semesan, or Bayer Compound or in 0.25 per cent solution of Germisan, Corona 620, or Tillantin "C" with 2.5–7.5 per cent smut from untreated seed.

Among 40 dusts tested, Abavit B, Trockenbeize Tillantin, and Wa Wa reduced covered smut to a slight trace without seed injury and also reduced loose smut from 0.7 per cent to a slight trace. Untreated seed produced from 3.6 to 12.2 per cent heads affected with covered smut.

For controlling stinking smut of wheat, 44 dusts were tested. Perfect control was obtained without seed injury with Abavit B, Trockenbeize Tillantin, Wa Wa, Vitrioline, S. F. A. 225 and 225 V, Dupont 68, and Ceresan. Commercial control was obtained with copper carbonate in all cases except one in 1927, when copper carbonate containing 18 per cent copper reduced stinking smut from 25 to 8 per cent. Heavy rains after sowing doubtless were responsible for this failure.

Copper carbonate does not deteriorate with age but some other dusts do. Extremes of soil reaction did not affect the fungicidal efficiency of the dusts used. Very dry soil conditions during germination and emergence reduced fungicidal action of the dusts.

Experiments on stripe disease of barley and its control. R. W. LEUKEL, J. G. DICKSON, and A. G. JOHNSON.

Over 50 dust disinfectants of American and foreign manufacture were tested for the control of stripe disease in several varieties of barley. Ceresan, Trockenbeize Tillantin, and Wa Wa practically eliminated stripe in every trial. Abavit B, Tutan, Semesan, Mercury "C," S. F. A. 225 V, and several experimental dusts were usually effective in stripe control but not consistently so. Uspulun, Germisan, and Semesan used in solution were effective as heretofore. The age of the seed showed no relation to the effectiveness of the fungicides used.

The dusts did not greatly increase either germination or stand. Yield, however, was increased by the effective treatments, both with liquids and dusts.

Relatively dry soil (less than 20 per cent saturation) during the period of emergence seemed to favor stripe development as compared with very wet soil. Stripe developed most abundantly at or below 15° C., some occurred at 20° C., a trace at 24° C. and none at 28° C. Changing the soil temperature from 12° C. to 28° C., or vice versa, after the first-leaf stage did not affect the percentage of stripe. (Cooperative investigations between Wisconsin Agricultural Experiment Station and Office of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture.)

Preliminary report on a bacterial disease of corn. A. G. JOHNSON, LILLIAN CASH, and W. A. GARDNER.

In June a disease of corn, now known to be caused by bacteria, was reported from Baldwin County, Alabama, by County Agent S. H. Gibbons. Later, what seems to be the same disease was found to limited extent on Arlington Farm, Va.

The disease manifested itself as a stalk rot of upper part of stalk and as a leaf blight. The stalk rot occurred usually at or just above where ears are produced, causing dark brown soft rot of internodal pith with no infection in lower part of such stalks. This rotting usually killed the tops before or just after tassel emergence, producing the effect of marked dwarfing of plants. Leaf blight occurred on middle and upper leaves. Lesions were usually stripes of various widths and lengths, sometimes coalescing and

killing greater portions of some leaf blades. The younger lesions were watersoaked; older lesions were dry in centers, light tan with sepia margins. Later, attacked leaves became greatly shredded. Microscopic examination of young lesions showed invaded tissues teeming with bacteria.

Numerous isolations have been made and some cultures have proved pathogenic on both leaves and stalks.

Both the disease manifestations and the organism apparently differ distinctly from those of the bacterial stalk rot previously described by Rosen. (Cooperative investigations between Alabama Agricultural Experiment Station and Office of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture.)

Another bacterial leaf spot of sorghum. CHARLOTTE ELLIOTT.

This disease, observed in Texas, Oklahoma, and Kansas, is characterized by dark reddish brown streaks on the leaves of *Holcus sorghum*. The youngest lesions are narrow, watersoaked streaks. Narrow margins or blotches of reddish brown soon appear in these streaks, and in a few days the red color is continuous throughout the lesions. At intervals these red streaks broaden out into elongated oval spots with tan centers and narrow red margins. Exudate is abundant and dries down to white or cream-colored scales. Isolations have given pure cultures of a yellow organism, the pathogenicity of which has been proved. The organism is apparently undescribed.

Net-necrosis of Irish potato tubers. G. H. GILBERT.

Net-necrosis of potatoes, consisting in the appearance of a network of brown strands in the vascular region of the tuber, is shown to involve the sieve-tubes, companion cells, and adjacent cells of the phloem parenchyma which together constitute the brown strands that are evident when the skin and outer cortex of affected tubers are removed. Earliest indications of necrotic changes are the occurrence of dead and discolored protoplasmic contents of sieve-tubes and companion-cells. Later larger areas occur, as a result of the merging of smaller spots. Necrotic areas are frequently separated from surrounding normal tissue by the formation of cork cambium walls.

Microchemical tests show that changes in necrotic walls involve accumulations of suberin, lignin, and pectic substances and result in strong resistance to cell-wall solvents.

Field experiments have further confirmed the hypothesis that net-necrosis of the tuber is correlated with leafroll and particularly that it is a first-season symptom following initial leafroll infection. Characteristic necrosis was produced under controlled conditions following the transfer of aphids from leafroll to healthy plants in cages, while tubers from control plants remained free from the disease.

Apical leafroll of potato. E. S. SCHULTZ and REINER BONDE.

Apical leafroll, a new potato disease, is related to the leafroll group of virus diseases. Infected plants slightly dwarfed manifest roll of the upper leaves similar to primary leafroll, and to the roll of the apical leaves frequently associated with rhizoctonia and similar diseases. However, apical leafroll is distinguished from primary leafroll by persisting only on the upper leaves in succeeding generations. The tubers, reduced in size but normal in shape and number, are frequently but not invariably attached to short stolons resembling the rather clustered tuber set of witches'-broom plants. Apical leafroll plants are distinguished from those affected with witches' broom by taller, more vigorous, and fewer shoots which form larger and fewer tubers.

Observations on apical leafroll during four seasons have disclosed that it is perpetuated through the tubers and that it can be transmitted to healthy potatoes by tuber grafts. Experience with Green Mountain, Rose No. 4, Irish Cobbler, and Bliss Triumph varieties has shown that they are susceptible to this disease and that, although Green Mountain and Rose No. 4 manifest the foliage symptoms earlier in the season than the other varieties mentioned, the most conspicuous symptoms appear too late in the growing season to insure effective control.

Calcium arsenate as a fungicide. H. H. WHETZEL, S. E. A. MCCALLAN, and T. C. LOH.

In spraying and dusting tests during the summer of 1928 on the control of *Alternaria panax* on ginseng, it was found that Pyrox entirely prevented infection by this pathogene. Bordeaux mixture (4–4–50) and copper lime dust (20–80) gave little control, merely retarding somewhat the final destruction of the stems and foliage. Laboratory tests with these fungicides using spores of *Alternaria panax* indicate that the effective fungicidal agent in the Pyrox, as far as this fungus is concerned, is the arsenate of lime rather than the copper. Arsenate of lead which is also present in Pyrox showed but little toxic action on the spores of this fungus. A 1 per cent mixture of calcium arsenate in talc proved to be more toxic to the spores of this fungus than a 4–4–50 bordeaux mixture. Since it is well known that Alternaria pathogenes are in general not easily controlled with copper protectants, the evidence in this case points to the possibility of more effective control of diseases such as early blight of potatoes by the use of calcium arsenate alone or in combination with copper protectants.

A preliminary report on forced-air ventilation for the control of Cladosporium leaf mold of greenhouse tomatoes. A. G. NEWHALL and J. D. WILSON.

All attempts to control Cladosporium leaf mold of greenhouse tomatoes by spraying or dusting with either copper or sulfur fungicides have failed.

The conidia will germinate over a temperature range from 6° to 29° C. They require a relative humidity above 96 per cent. Humidity is, therefore, of the greatest importance in determining the rate of spread of the disease.

Transpiration is found to be the greatest factor responsible for high humidities in greenhouses. As many as 400 gallons of water an hour have been computed to be given off by an acre of tomatoes under normal conditions in June. The problem of controlling leaf mold is therefore one of ridding the house of this excess water vapor and keeping the leaf surfaces comparatively dry.

Apparatus is being developed for studying the effects of different rates of air change under controlled humidities on spore germination and leaf mold development. A study has been made of the evaporating power of the air in a number of greenhouses equipped with forced-air ventilation systems of different types. Brief descriptions will be given of some of the installations now on trial in Ohio greenhouses with notes on costs, methods of operation, and yields.

Effects of some environmental factors on the root-knot nematode. G. H. GODFREY and HELENE T. MORITA.

Heterodera (*Caconema*) *radicicola* lives for months under favorable conditions. Egg masses may hatch 100 per cent under best conditions. Larvae are killed at 43° C. in 10 minutes and at 53° instantly. Egg masses are killed at 48° C. in 10 minutes and at 58° instantly. Complete dryness kills larvae in 3 minutes and egg masses in 2 hours. Drying at 70 per cent relative humidity kills larvae in 10 minutes and egg masses in 4 hours. Free eggs are killed more quickly than those in egg masses. Egg

masses buried within roots survive for 48 hours in complete dryness, for 5 days at 60 per cent, for 7 days at 70 per cent, and indefinitely at 90 to 99 per cent. Tests with sunlight and with ultra-violet lamp (moisture and temperature favorable) show that ultra-violet light kills nematodes. Sunlight killed larvae in 25 minutes, egg masses in 8 hours, free eggs in 1½ hours. Combined sunlight and drying killed larvae in 2 minutes, egg masses in 30 minutes, and eggs within roots in 8 hours. X-rays did not kill larvae or eggs in 35 minutes. In greenhouse tests with soils 10 inches deep, the organism was completely killed by 4 months' drying with stirring; when the soil was not stirred, so that the bottom was still moist and the humidity high in interspaces, there was only partial killing. Field results indicate practical application of this definite information.

A Fusarium disease of beans.—L. L. HARTER.

In August, 1928, a disease was observed for the first time in the Sacramento Valley of California on several varieties of field beans. Isolations made from the fibrovascular bundles from various parts of the stem gave in every case a species of *Fusarium* belonging apparently to the Elegans group. The fungus traverses the fibrovascular bundles throughout almost the entire length of the stem and extends into the branches and into the petioles of the leaves. The fibrovascular bundles are conspicuously discolored. The plants were not observed to wilt like most plants invaded by a vascular parasite. They were somewhat dwarfed. In the early stage the color of the leaves changed to pale green, later to a bright yellow. The leaves finally dried up and dropped off. Diseased plants could be recognized in the field at some distance by bright yellow foliage.

Inoculations have been made and typical symptoms of the disease produced. Specimens of diseased plants have not been collected outside of the Sacramento Valley.

Further studies on the control of stem rot of sweet potatoes. R. F. POOLE.

The stem rot, wilt, yellows, or root rot disease of sweet potatoes caused by *Fusarium batatatis* was controlled on farms in different parts of North Carolina by treating stems and roots with bordeaux mixture as described in 1927. A 20–20–50 bordeaux mixture gave the best control without injury. A 5–5–50 mixture gave some control, but less than the stronger mixtures. Slight injury was caused by a 50–50–50 mixture. A 25 per cent monohydrated copper-lime dust gave equally good control as the liquid treatments without causing injury in any test. These treatments were not effective when diseased plants were used. They did not increase or decrease production when the yields from treated plants were compared with healthy, untreated plants. Disease was controlled equally well in Porto Rico, Nancy Hall, and Yellow Jersey varieties.

Further studies on watermelon wilt in Iowa. D. R. PORTER and I. E. MELHUS.

In 1928 all local commercial varieties of watermelons tested proved to be susceptible, although individual plants of some appeared to be resistant. Two edible foreign varieties proved resistant. The variety Conqueror again failed to show appreciable resistance, but the F_2 generation of some Kleckley-Conqueror crosses appeared to possess considerable resistance. Seven citron strains were tested and six of them proved almost immune. The F_2 generation of Kleckley-citron (variety Kafir) crosses proved to be 86 per cent resistant, but few of the melons were edible.

One hundred per cent wilt occurred after 22 days when seed of the variety Tom Watson was planted in infested soil kept between 22° and 25° C. In soil kept between 16° and 19° C., none of the Tom Watson plants wilted after 22 days and only 51 per cent after 49 days. In soil kept between 22° and 25° C., none of the stock citron plants wilted after 22 days and only 21 per cent after 30 days.

Chemical injury to watermelons in transit—results of shipping tests. W. W. GILBERT and F. C. MEIER.

In 1925 a report was made on experiments to determine whether chemicals commonly hauled in freight cars are able to injure watermelons subsequently loaded in such cars, and if so, the extent and character of this injury. In the course of two years' tests under actual shipping conditions, the results indicate that certain chemicals, or commercial fertilizers containing one or more of them, are dangerous when present on the walls and floor of the car. By using ample dry bedding, injury to melons was avoided.

When scant dry bedding was used, serious injury (discoloration, pitting, softening) was caused by common salt, sodium nitrate, acid phosphate, ammonium sulfate, potassium sulfate, and potassium muriate. Injury was more severe than results of earlier stationary tests had indicated would be the case. Greater injury was caused if the bedding was damp when the melons were loaded. In none of the tests was serious injury caused by hydrated lime or pulverized road lime, though slight superficial damage resulted when wet bedding was used. The results point to the necessity of cleaning cars thoroughly before loading, and using ample bedding, that is, the equivalent of two to three 75-lb. bales of straw.

A fruit rot of honey dew melons due to a species of Phytophthora. CHARLES DRECHSLER.

From the decayed tissue of a large lesion appearing externally as an extensive, somewhat depressed, water-soaked region on a honey dew melon, *Cucumis melo* var. *inodorus*, originating presumably in California or Colorado, was isolated in Washington, D. C., Sept. 15, 1926, a species of *Phytophthora* producing on irrigated lima bean agar prominently papillate zoosporangia with an average length of 57 μ and an average diameter of 30 μ. The fungus, on inoculation into healthy fruits, proved an efficient parasite in causing a decay similar to that present in the original specimen. Too great a specificity should not be attributed to the pathogenicity thus evidenced, since the large majority of fungi referable to the genus *Phytophthora* appear to be capable of inducing identical pathological effects with greater or less rapidity. Among the more rapidly destructive of congeneric parasites are to be included, for example, *P. cactorum* (Cohn & Leb.) Schroet., *P. citrophthora* (Sm. & Sm.) Leon., *P. melongenae* Saw., *P. parasitica* Dastur, and *P. terrestris* Sherb.

Breeding for resistance to cucumber mosaic disease. E. E. CLAYTON.

On Long Island, cucumber mosaic is regular in its occurrence, and attempts to control it by weed eradication have failed completely. This is a first report on an attempt during four years to select, out of the standard pickling and slicing varieties, strains that are mosaic resistant. Inbreeding did not reduce plant vigor but did bring out many abnormalities, particularly in fruits, *i.e.*, albino, spiny, and misshapen types. Off-type lines were discarded and the desirable ones tested for resistance to downy mildew (*Pseudoperonospora cubensis*) and bacterial wilt (*Bacillus tracheiphilus*) as well as mosaic. All lines have proved equally susceptible to mildew. Numerous lines showed extreme susceptibility to wilt, and a few showed moderate resistance. Lines that show distinct mosaic resistance were secured, as well as many that were extremely susceptible. The development of mosaic-resistant varieties similar in type to varieties now in commercial use appears entirely practicable.

Reaction of Chinese cucumbers to mosaic. R. H. PORTER.

In the summer of 1928 an occasional plant of the cucumber variety Chinese Long (collected at Nanking, China, by the writer in 1926) following inoculation with mosaic

virus from the variety Chicago Special developed a faint mottling which was frequently difficult to detect. Attempts to transfer the virus from such plants to susceptible American varieties were successful to the extent that 80–100 per cent of the plants inoculated developed mosaic. Later it was found that some plants of the Chinese cucumber developed a decided crinkling of the terminal leaves without showing any yellowing or mottling. Transfers from such plants to American varieties proved the presence of the mosaic virus. In no case has "white pickle" or stunting of any of the Chinese plants been observed either in the field or greenhouse, such as commonly occurs on American sorts. The percentage of plants in this Chinese variety which develop either mottling or crinkling after inoculation is low, probably not over 15 per cent. The incubation period required for development of symptoms also averages longer than in American varieties. The above-described symptoms disappear within 5–15 days, even when the plants continue to grow vigorously.

The yellow dwarf of onions. I. E. MELHUS and W. J. HENDERSON.

A new disease of onions, first noted in 1927, became epidemic in the Pleasant Valley district, in Iowa, in 1928. It is characterized by stunting of bulbs, and crinkling, yellowing, and drooping of leaves. The prevalence of the disease varies from a trace to 95 per cent of the plants infected. It appeared first in a low place where the water had run over the field and was most severe in areas that had been flooded. Evidence to date indicates that the disease is not seed borne. It is carried in the vegetative stage, sets, and mother bulbs. Inoculation trials with juice of diseased onions show that it is a transmissible virus disease. The incubation period is about 12 days. In trials involving 700 sets, 34.3 per cent became infected as a result of injecting the juice of diseased onions into buds of the sets before planting. Inoculation trials on tomato, cucumber, tobacco, and squash have not been successful. The name "yellow dwarf" is proposed.

Toxicity of mercury and copper compounds in relation to their use for seed treatment and spraying. E. E. CLAYTON.

Many recommendations for spraying and seed treatment involve the use of copper and mercury compounds in concentrations likely to be toxic to plants. These effects are complicated and often not at once evident. Thus lima bean seed dusted with a mercury compound may germinate well but the plants produced are smaller and yield less than those from untreated seed. Again, healthy gladiolus corms soaked 7 hours in 2.0 per cent Semesan were never killed, but they failed to produce as large plants or flowers as the untreated. Species vary in susceptibility to injury, and closely related forms may react quite differently. Thus, while lima beans were mercury-sensitive, string beans were not. Comparing the seed and the growing plant, tomato seed was sensitive to injury from mercury disinfectants and tomato plants resistant to injury from mercury sprays. Cucumber and cantaloupe seed were resistant to injury from mercury and copper disinfectants but the plants were sensitive to injury from the sprays. More fundamental knowledge of the behavior of copper and mercury as plant poisons will make possible safer and more effective use of control measures.

Progress report on studies of fireblight of apple. P. W. MILLER.

The results of three years' study of the epidemiology of fireblight of apple show that, under Wisconsin conditions, meteoric water is an important agency in disseminating the primary and the secondary inoculum. The rôle of insects in disseminating fireblight appears to be less important than was earlier believed and needs to be re-evaluated.

Abundant infection of young shoots and unopened blossom buds on potted apple and pear trees grown in the greenhouse under conditions designed to prevent injury by insects and other agencies has been induced at will by spraying them with a pure suspension of *B. amylovorus* in sterile distilled water and placing them in a moist chamber at suitable temperatures. Numerous cases of stomatal penetration have been found in histological studies of tissues taken from (a) inoculated young apple leaves, (b) the sepals of inoculated unopened apple flowers, and (c) the inside of the receptacle cups of apple and pear flowers that were open when inoculated.

These results seem considerably to enhance the possibility of using the excision method as one part of a successful control program. Strong potentialities appear to lie in the use of chemical treatments designed to inactivate such primary inoculum as escapes the excision process.

Rust diseases of the apple. H. E. THOMAS and W. D. MILLS.

Three rust diseases are destructive to the apple in eastern New York State: apple rust caused by *Gymnosporangium juniperi-virginianae* Schw., hawthorne rust caused by *G. globosum* Farl., and quince rust caused by *G. germinale* (Schw.) Kern. Quince rust has been found on the fruit of five varieties of apples, causing heavy losses. The symptoms vary widely from one variety to another. Hawthorne rust occurs on the foliage of at least 13 varieties. In a few instances the infection is severe. Apple rust has been unusually abundant on both fruit and foliage in 1927 and 1928. The peridial cells of the fungi seem to offer the most distinct diagnostic characters.

Studies of the fungicidal action of certain dusts and sprays in the control of apple scab. J. M. HAMILTON.

The investigation was conducted in the greenhouse on the leaves of potted apple plants under controlled conditions in order to relate fungicidal applications with the experimental production of disease as desired. Leaves treated with sulphur dusts or lime-sulphur spray before infection were efficiently protected until resistant. Sprays containing lime-sulphur gave good control when applied 72 hours after inoculation and in such treatments were consistently more effective than the sulphur dusts, colloidal sulphur sprays, copper fungicides, oils, and proprietary mercury compounds tested.

Temperature appeared to influence the development of host and parasite and progress of disease more than it affected the fungicidal action of sulphur.

No significant increase in fungicidal efficiency of sulphur followed the addition of potassium permanganate to sulphur as an oxidizing agent.

After various fungicidal treatments potted plants were washed and inoculated. Bordeaux mixture and sprays containing lime-sulphur were found to be decidedly more adhesive than certain sulphur dusts, colloidal sulphur sprays, oils and other combinations. The addition of emulsified oil and certain other materials increased the effectiveness of certain fungicides.

Laboratory studies corroborated the greenhouse studies of the sulphur fungicides with respect to the relation of temperature and the addition of potassium permanganate.

Third progress report of studies of fall applications of fungicides in relation to apple scab control. G. W. KEITT and E. E. WILSON.

In 1927, in continuation of studies which have been reported (Phytopath **17**: 45 and **18**: 146), scabbed apple leaves were sprayed with various fungicides after harvest and before leaf-fall. Representative samples of control and treated leaves were overwintered and studied for the development of perithecia of *Venturia inaequalis*. Many of the com-

pounds tested showed some value in suppressing the development of the perithecia. Calcium arsenite (probably chiefly ortho) gave very promising results. In several tests, calcium arsenite, in concentrations varying from 0.25 to 1 per cent, alone or mixed with other materials, reduced the number of perithecia to less than one-tenth the number which developed in the controls. Certain of these calcium arsenite preparations have caused serious host injury, while others have been applied with a power sprayer to orchard trees without evidence of injury in the following season. Because of the high toxicity of calcium arsenite, it is not yet recommended for commercial trial, and caution in its experimental use is advised.

The effect of sprays on the weight of cherry fruit. E. E. WILSON and G. W. KEITT.

Studies of the weight of cherry fruits from trees which had been sprayed comparatively with bordeaux mixture and lime-sulphur, respectively, have been conducted for the past five years. The results have varied considerably from year to year and orchard to orchard. In general, fruits from trees sprayed with lime-sulphur were somewhat heavier than those from trees sprayed with bordeaux mixture. The increased weights of lime-sulphur over bordeaux sprayed fruits from Montmorency trees were as follows for the following years: 1924, 15 per cent; 1925, 13 per cent; 1926, 9 per cent; 1927, 16 per cent; 1928 (average of four orchards) 8 per cent. The increased weights of lime-sulphur over bordeaux sprayed fruits in four orchards in 1928 were as follows for the following varieties: Early Richmond, 1 per cent, 4 per cent, 6 per cent, 8 per cent; Montmorency, 2 per cent, 6 per cent, 11 per cent, 13 per cent. This increase in weight in 1928 appeared to be due to increase in the fleshy part of the fruit, as no significant difference could be found in the weight of pits of fruits from trees receiving the two different treatments.

The influence of the form and proportion of lime and copper sulphate on the suspension of bordeaux mixture. F. J. SCHNEIDERHAN.

Approximately 1,000 tests of bordeaux mixture, prepared according to 30 different formulas and from different forms of lime and copper sulphate, were made to determine suspension percentages. Stone lime, hydrated (finishing) lime, chemical hydrated lime, crystalline copper sulphate, powdered copper sulphate, and dehydrated copper sulphate were used, both in stock solutions and by combination in dry form. The highest ratio between suspended bordeaux and the total volume of liquid was found when chemical hydrated lime and finely granulated copper sulphate were used according to the formula 2–3½–50. A close correlation between fineness of lime particles, its chemical composition (especially the CaO content) and suspension ratios exists. Chemical hydrated lime containing 72.7 per cent CaO; 98.74 per cent passing through a 325-mesh sieve and with a volume of 3.04 cc. per gram, when used in combination with finely granulated copper sulphate resulted in a maximum suspension of 98.8 per cent after one hour, 97.6 per cent after two hours and 95.2 per cent after three hours. The same materials used in 2–4–50, 3–4–50, 3–5–50, and 1–1–50 bordeaux gave suspension ratios nearly as high as the 2–3½–50 and considerably higher than any formula of bordeaux prepared from slaked stone lime and copper sulphate in stock solutions. Excellent fungicidal properties of "Instant" bordeaux prepared from powdered materials have been demonstrated in the control of apple blotch (*Phyllosticta solitaria*) during two years.

Dusts composed of lime-sulphur and sulphur. H. C. YOUNG.

Four sulphur dust combinations with finely ground dry lime sulphur were tested for control of apple scab. These were 85–15 and 90–10 sulphur-dry lime sulphur, 85–10–5 sulphur-dry lime sulphur-bentonite, and 85–10–5 sulphur-dry lime sulphur-hydrated

lime. The 85–15 combination gave excellent control during a season that was exceptionally favorable for scab development. This dust proved superior to any others used except the oxidized sulphur dusts.

Chemistry of the toxic factor of sulphur. R. C. WILLIAMS and H. C. YOUNG.

Studies on the chemistry of the toxic factor of sulphur have been continued. Ordinary ground roll and flowers of sulphur were found to yield varying amounts of the toxic factor depending upon reaction, oxidation, temperature, and moisture. Sulphurs treated with such oxidizing agents as potassium permanganate, manganese dioxide, and arsenious acid were found to be extremely toxic. All known acids associated with sulphur were analyzed and tested for their toxicity and the only ones found toxic were the polythionic (tetra and penta) acids. All sulphurs freed from these acids were nontoxic to *Venturia inaequalis*. Several oxidized sulphur dusts were tried in the field and found effective in the control of apple scab. It was found further that the toxic factor was destroyed by alkalis and strong acids.

Adhesiveness of sulphur mixtures. H. C. YOUNG and L. E. TISDALE.

It was found in this work that materials such as bentonite, kaolin, hydrated lime, gypsum, glue, or any other type of so-called stickers and fluffers do not enhance the adhesiveness of 300-mesh ground roll sulphur. Particulate sulphur stuck better than coarse particles. Sulphur found on leaves after heavy rains was in a very fine state, about 600 mesh. Different types of rains influenced the adhesiveness of sulphur, a heavy downpour washing off less sulphur than the same amount of water falling more slowly and over a longer period. It was found that when a heavy coating of sulphur dust was applied to leaves or slides less would remain after rains than when smaller amounts were applied. Apparatus and methods for slide determination of sulphur adhesiveness are described.

Some raspberry mosaic symptoms. C. W. BENNETT.

Further experimental results in the transmission of raspberry mosaics indicate that symptoms of mottling may be caused by a larger number of viruses than has heretofore been recognized. The terms yellow, mild, and red raspberry mosaic may be used to indicate groups of related symptoms, with no clear line of separation, however, between the more severe forms of mild mosaic and the lighter forms of red raspberry mosaic. Yellow mosaic seems to be a very definite type distinguishable from the other mosaics by color of foliage, time of incubation, and rate of dispersion of the virus in the plant. Viruses of this type seem to be much more virulent from some sources than from others. Other mosaics differ chiefly in severity of symptoms. There is a wide range of effect produced, varying from a very light mottling in the milder forms to a severe leaf distortion and cane-tip necrosis which has been described in red raspberry mosaic. Frequently, viruses of these types are combined with yellow mosaic, from which they can be separated by virtue of their more rapid movement. Plants affected by the milder forms remain susceptible to infection by more severe types; thus some of the severe types of mosaic may be caused by a combination of two or more viruses.

Decay of citrus fruits in transit. HARRY R. FULTON and JOHN J. BOWMAN.

The rots here considered are caused by *Penicillium digitatum, P. italicum, Phomopsis* (*Diaporthe*) *citri*, and *Diplodia natalensis*. Data are given showing the prevalence of these rots on arrival at destination, and the degree to which various amounts of decay depress the market price. This price depression measures financial loss, and sets limits

to the profitable employment of control measures. Relative effectiveness of various control measures is discussed, based on experiments extending over many years. These show (1) that Diplodia stem-end rot may be reduced 50 per cent or more by early spring removal of dead wood in which the fungus sporulates, (2) that Phomopsis stem-end rot may be reduced 50 per cent or more by a one application of bordeaux mixture to the very young fruit, (3) that both types of stem-end rot can be reduced 90 per cent or more by prompt removal of the stem "buttons" after picking, (4) that chemical treatments in packing houses can reduce stem-end rots and blue mold rots very greatly, (5) that precooling and refrigeration are important protective measures during transit and marketing, (6) that promptness and care in handling at all stages are essential in successfully combatting rots of citrus fruits.

Further studies on Exoascaceae. A. J. MIX.

Attempts to isolate *Exoascus deformans* and *E. mirabilis* from fragments of diseased tissue are successful only when asci form on these fragments in culture and ascospores are shot on to the agar.

Conidia of *E. deformans* formed in culture are uninucleate. Nuclear division occurs in the budding conidium and a daughter nucleus passes into the bud. Copulating conidia and long germ tubes with binucleate cells as reported by Wieben for *Taphrina epiphylla* and *T. klebahni* have been observed. Cells from culture, previously called resting cells, are believed to be ascogenous cells. They show paired nuclei, fusing nuclei, or a large single nucleus. Binucleate hyphae with plate septa and structures believed to be imperfect asci have also been found. Apparently growth in culture must be initiated by the haploid (saprophytic) stage, but, in established cultures, cells belonging to the diploid generation occur.

Exoascaceae thus far cultured include: *Exoascus deformans, E. mirabilis,* and *E. mirabilis* var. *tortilis* from *Prunus angustifolia, E. pruni* from *P. domestica, Exoascus sp.* from *Alnus incana* and *A. rugosa, E. communis* from *Prunus americana,* and *Taphrina coerulescens* from *Quercus rubra.* The two last-named forms do not agree in cultural characters with cultures described by Martin as of *Taphrina communis* from *Prunus americana,* and *T. coerulescens* from *Quercus rubra* and *Q. nigra.*

A disease of tobacco seedlings caused by Septomyxa affinis (Sherb.) Wr. W. B. TISDALE.

Each year since the initiation of tobacco investigations in Florida a disease of tobacco seedlings has been observed in several seed beds on new land. The disease usually occurs in portions of the beds partially shaded by trees, but in 1928 under very humid conditions entire beds were invaded. Infected areas of the beds are conspicuous because of the yellowed and stunted condition of the plants. The disease is characterized by more or less irregular, olivaceous blotches on the upper surface of the leaves and blotches or streaks of similar characters on the petioles and stems. Under humid conditions the affected parts develop a soft rot, resulting in a ragged appearance of the leaves and the damping off of the petioles and stems. Plants artificially inoculated with spores of the fungus and kept under humid conditions in the greenhouse develop severe damping off within five days. Slightly infected plants recover when transplanted to the field.

A similar disease of tobacco seedlings has been reported from Connecticut, Kentucky, and Ohio and has been attributed to a species of *Fusarium.* A study of the morphological characters of the fungus shows that it closely resembles *Fusarium affine* Sherb., which according to Wollenweber's new combination becomes *Septomyxa affinis* (Sherb.) Wr.

Studies in the physiology and cytology of Ustilago zeae and Sorosporium reilianum. W. F. HANNA.

The sporidia of *U. zeae* are haploid. Corn plants inoculated with monosporidial cultures never produce galls, but those inoculated with mixtures of certain pairs of monosporidial cultures produce galls which bear mature chlamydospores. On germination, some chlamydospores give rise to two pairs of sporidia of opposite sex; the sporidia from other chlamydospores may belong to four sexual groups. Segregation of factors may occur at both divisions of the spore nucleus. Sporidial conjugation has not been observed. The germ tube from a haploid sporidium is able to penetrate the epidermis of a young corn leaf. The diploid mycelium is initiated by a fusion of the germ tubes from two sporidia of opposite sex.

S. reilianum is heterothallic. Sporidia of four sexual groups may be produced from a single chlamydospore. Young corn plants develop galls only when inoculated with a combination of two monosporidial cultures of opposite sex.

Single monosporidial cultures of *U. zeae* and *S. reilianum* were mixed together and injected into young corn plants, but none of the inoculated plants developed galls.

Pathogenicity of multisporidial and monosporidial cultures of Ustilago zeae (Beckm.) Ung. A. H. EDDINS.

Five multisporidial cultures of *Ustilago zeae* isolated from one smut gall differed in pathogenicity when seedling plants of inbred lines of corn were inoculated hypodermically with conidial suspensions of these cultures.

Five monosporidial cultures derived by a dilution method from multisporidial cultures failed to produce smut galls on plants of five inbred lines of corn. When the inoculum of each of the monosporidial cultures was mixed with each of the other cultures, it was found that certain of the paired combinations produced chlamydospores in host tissue while other combinations did not. These results indicate that a culture originating from a single sporidium constitutes a sexual strain of the fungus. The five cultures were found to represent four such strains and were designated A, B, C, and D. Chlamydospores were produced in host tissue when A was paired with C, but not when paired with B and D. Chlamydospores were produced also when B was paired with C and D. No chlamydospores were produced when C was paired with D.

A fungous disease of conifers related to the snow cover. J. H. FAULL.

A disease of conifers, especially devastating to the spruces other than black, occurs in the snow-laden parts of Northeastern America, and it may occur in the West. It is due to a *Phacidium* that answers to *P. infestans*. The form as found everywhere on balsam may be the same as Weir's variety *abictis* on western *Abies*. *Phacidium* blight attacks *Abies*, *Picea*, *Thuja*, and *Pinus* sporadically in the native forests, but the spruces, and particularly white spruce, to an alarming extent when the blight gets a foothold in nurseries and plantations. The disease develops and spreads by mycelium under the snow cover in early spring, but not during the summer. Primary infection from ascospores probably takes place in the autumn.

Perfect control has been attained by spraying in the late fall with lime sulphur, and by suitable sanitation measures. Such control has almost completely eliminated the disease from certain affected nurseries and plantations. Without control in these areas, the success of reforestation with white spruce at least is gravely doubtful.

The development of the spores of Plasmodiophora vascularum. MELVILLE T. COOK.

Plasmodiophora vascularum is a plasmodium which lives in the tracheary tissue of the sugar-cane, but which does not cause a hypertrophy. The plasmodium produces a

number of uninuclear masses which appear to be slightly amoeboid. They increase in size and produce thick cell walls. The spores form short germ tubes. The organism travels through the tracheary tissue to a considerable height in the plant. It is distributed in the seed-cuttings and possibly in other ways.

A diplanetic species of Phytophthora causing pink rot of potato tubers. CHARLES DRECHSLER.

A species of *Phytophthora* with prominently papillate zoosporangia averaging approximately 54 μ in length and 37 μ in diameter was isolated from potato tubers affected with watery decay originating near Ft. Gibson, Oklahoma, June, 1923, and from tubers showing mealy pink rot originating near Louisville, Kentucky, August, 1923. On artificial inoculation it causes pink rot evidenced internally by purplish discoloration of eyes and in death of buds; while cut affected tissues on exposure to air rapidly turn pink and later blackish. Though similar pathological effects are produced also on inoculation not only with *Phytophthora erythroseptica* Pethy., but also with such congeneric types as *P. cactorum* (Cohn & Leb.) Schroet., *P. cinnamomi* Rands, *P. citrophthora* (Sm. & Sm.) Leon., *P. cryptogea* Pethy. & Laff., *P. melongenae* Saw., *P. parasitica* Dastur, *P. parasitica* var. *rhei* Godfrey, and *P. terrestris* Sherb., the fungus exhibits considerable specific distinctiveness in energetic diplanetism. Primary zoospores after rounding up yield secondary ones by direct delivery of the protoplast through an evacuation tube 3 μ wide and 1–7 μ long; or less directly by the production terminally on a pedicel 1.5 μ wide and 5–25 μ long of a definitely papillate, ovoid, 1-spored germ-sporangium delimited by a basal septum. The latter manner of development, exceedingly frequent with zoospores imprisoned within primary sporangia through partial or complete frustration of normal discharge, results often in a novel reproductive arrangement. Diplanetism in some measure occurs elsewhere in the genus, as, for example, in a form referable apparently to *P. erythroseptica* and isolated earlier from Idaho potatoes by G. K. K. Link.

A Stemphylium leaf spot of tomatoes. GEORGE F. WEBER.

An undescribed leaf disease of tomatoes has been noted in Florida during late spring and early summer for the past five seasons. Primary infection takes place on the leaves near the soil surface in the seed bed or in the field. Secondary infection rapidly involves the entire foliage, the disease being most conspicuous on the topmost leaves. The spots produced by the fungus are sunken, grayish in the center, and surrounded by a dark band. They are small, usually 1–4 mm. in diameter and may be round, oval, or irregular. Repeated isolation from spotted leaves consistently yielded the organism, which grows well and sporulates readily on potato-dextrose agar. The organism remained viable at 5° C., but showed little or no growth below 10° C. Its optimum temperature ranged between 23° and 26° C., with the maximum temperature for growth below 35° C. Optimum temperature for sporulation was 32° C. The hyphae, conidiophores and conidia are fuliginous and septate, and the conidia are muriform. The conidia germinate readily in 2–6 hours in water. Inoculation experiments have proved its parasitism on several tomato varieties, as well as peppers, ground cherries, eggplants, and *Solanum floridanum*. Bordeaux mixture 4–4–50 applied weekly after plants are up has proved to be the best fungicide for the control of this disease.

Local symptoms of mosaic in the leaves of some Nicotiana species. F. O. HOLMES.

At least five species of *Nicotiana* show necrotic local lesions where tobacco mosaic virus successfully enters their leaf tissues. These species are *Nicotiana rustica, N. acuminata, N. langsdorffii, N. sanderae,* and *N. glutinosa. Nicotiana glutinosa* shows

pronounced localization of symptoms on the leaf inoculated. The young leaves near the growing point usually show no evidence of the disease. This extreme localization is correlated with rapidity of development of the necrotic lesions, which appear about 30 hours after inoculation and are fully formed in 4 to 5 days. The lesions are useful for measuring virus concentrations, for studying methods of inoculation, and for the isolation of pure lines of virus. *Nicotiana tabacum* does not show necrotic lesions, but gives evidence of the effect of the virus at the site of inoculation by changes in leaf color and amount of starch formation.

Are blackfire and angular leaf spot of tobacco identical? W. D. VALLEAU.

Attempts to control blackfire of dark tobacco by means of sanitary measures designed to exclude *Bacterium angulatum* from the plant bed, while often giving favorable results in controlling true angular leaf spot, have evidently failed to control blackfire, as it occurs following topping and suckering. Results of field, isolation, and inoculation studies and pot-culture work raise the question as to whether angular leaf spot and blackfire are not distinct diseases, the former bacterial and the latter physiological, and associated with certain nutritional and seasonal conditions. In pot cultures with a soil low in available nitrogen, spots similar to those of blackfire have developed following rapid growth which resulted from heavy applications of a nitrogen fertilizer, whereas the spots have been prevented by a single further application. Field-plot results in Kentucky and elsewhere suggest a relation between potash applications and control. Heavy applications of stable manure appear to control blackfire. Isolations from recently developed blackfire spots have failed to yield *Bact. angulatum*, while older spots sometimes appear to be contaminated with this organism. The blackfire or physiological type of spot is characterized by concentric rings, while typical angular leaf spots, as they occur in the field or result from inoculations, are not zonate.

Progress in the control of black shank of tobacco through disease resistance. W. B. TISDALE.

The original selections in the development of a strain of Big Cuba tobacco resistant to black shank (*Phytophthora nicotianae* Breda de Haan) were made in 1922. From one of these selections a highly resistant strain of merchantable quality has been developed. Attempts to isolate resistant strains of other varieties of cigar-wrapper tobacco by selection have been less successful. Since Big Cuba tobacco is considered of relatively mediocre quality, crosses have been made in an effort to combine its resistance with the superior quality of leaf of certain susceptible varieties.

Certain F_3 selections of the progeny resulting from a cross between resistant Big Cuba and Cuban have shown 98 per cent resistance and a quality of leaf superior to Big Cuba. Crosses between resistant Big Cuba and Connecticut Round Tip have proved less successful. Certain F_3 selections of progeny resulting from crosses between F_1 individuals of the Big Cuba-Cuban and Big Cuba-Round Tip progenies were practically immune to black shank and a leaf quality superior to that of any type tested.

The black-shank of tobacco in Porto Rico. J. A. B. NOLLA.

During the past two years a disease of tobacco known in Porto Rico as "pata-prieta," and probably the same as black-shank in the United States, has been studied. Plants of all ages are affected, the disease being especially destructive in seedbeds. The pathogene has been found to be *Phytophthora nicotiana* Breda de Haan. The Porto Rican fungus is supposed to be a slightly different strain from that causing a

similar malady in Florida. The pathogene seems able to produce a diseased condition in *Ricinus communis*, eggplant, pepper and tomato seedlings, and in potato plants.

The disease attacks both the cigar-binder and cigar-filler tobacco varieties. A non-commercial mammoth variety and the cigar-binder (Connecticut Round Tip) have proved most susceptible. A Porto Rican binder variety has shown high resistance.

Moisture is a dominant factor in outbreaks of damping-off caused by this pathogene; irrigation water is an important transportation agent.

As control measures are recommended: removal of diseased individuals, selection of seedlings, dipping healthy seedlings from diseased beds in bordeaux mixture (4–4–50 or 5–5–50) and the development of resistant varieties.

Verticillium wilt of cotton. C. D. SHERBAKOFF.

So far as known the first report on the occurrence of cotton wilt caused by *Verticillium alboatrum* (Reinke & Berth.) was made by the author in 1928 (Plant Disease Reporter, Supplement 61: 283 and 284. July 1, 1928). The additional information obtained since then shows: first, that the disease is present not only in Lake County, Tenn., but also in other places along both banks of the Mississippi River on a similar type of soil—various grades of "gumbo"; and, second, that the main field symptoms of the disease that distinguish it from the wilt caused by *Fusarium vasinfectum* are complete shedding of the leaves, and noticeable shedding of young bolls before the withering of the tips and branches, and an absence of any discoloration of cambium, with frequent development of new branches at the base of the plant. In case of the wilt caused by *Fusarium*, no conspicuous leaf or boll shedding or production of new branches at the base was observed, while in case of Verticillium wilt a distinct discoloration of the cambium was always noticed. The discoloration of fibrovascular bundles is always present in both wilts though it seems to be more evenly distributed in the case of the Verticillium infection.

A nematode root lesion of pineapple and other crops. G. H. GODFREY.

One factor contributing to root failure in pineapples in Hawaii is a root lesion produced by a species of *Tylenchus*. Lesions on young roots are irregular, longitudinal, argus brown spots, from one to several millimeters long, extending through cortical parenchyma cells but not into the stele. The nematodes multiply and migrate in the cortex, destroying the cells, until finally the root is killed. Branch feeding roots are often greatly reduced in number. The nematodes are sluggish, and lightly infested roots grow away from them and continue to function. When soil infestation is sufficiently heavy so that numbers of nematodes invade root tips, severe injury results and further growth of the root is prevented. Nematode root knot checks forward growth, making conditions ideal for penetration and multiplication of the *Tylenchus*, which then rapidly breaks down the tissues. Presence of the *Tylenchus* in a gall is always indicated by a brownish color. The two nematodes together make a destructive combination. Other plants subject to attack are tomato (slightly), soybean, cowpea (very heavily), and many weeds. In contrast with *Heterodera* (*Caconema*) *radicicola* the *Tylenchus* is resistant to drying. Its numbers are greatly reduced, however, in moist soil fallow, probably by starvation.

Further studies on the dry-rot canker of sugar beets. C. M. TOMPKINS.

Additional observations and experiments have been made during the past two years on the dry-rot canker (*Corticium vagum*) of sugar beets, first described by Richards of the Utah Agricultural Experiment Station in 1921. In late summer of 1927, the disease

was found for the first time in southern Idaho, and also in the San Fernando Valley, Calif., where it assumed epidemic proportions. Marked differences exist between the type of canker produced on beets in California and that found in Utah and Idaho. Pure-culture work indicates that there are at least two distinct strains of the fungus which induce similar host responses. Apparently these strains become pathogenic only in the presence of high soil temperatures in midsummer, which would explain the lack of seedling sickness in soils known to harbor the fungus. Field inoculation experiments show that the mycelium can penetrate the periderm without previous mechanical or other injury to the beet root. The number of plants affected tends to increase each succeeding year in contaminated soils, indicating constant extension of the organism within the soil. Since carefully conducted experiments in Utah have proved that crop rotation measures are ineffective, development of resistant strains of sugar-beet seed probably offers the most promising method of control.

Delayed thinning as a means of controlling damping-off of sugar beets. S. B. NUCKOLS and C. M. TOMPKINS.

Damping-off of sugar-beet seedlings constitutes one of the main limiting factors in securing good beet stands. In a field or locality, the number of infected seedlings fluctuates with the soil and seasonal conditions. Infection varies from 1 to 50 per cent in the cotyledon stage, although in extreme cases it may be 90 or 100 per cent. Results of three years of experimental work in Utah and western Washington on a wide range of acid and alkaline soils, indicate that good stands may be obtained by delaying thinning until the seedlings have six leaves, even when fields have been 50 per cent infected in the cotyledon stage. During this interval of about 20 days, sick seedlings are eliminated by natural means. When thinning is done in the six-leaf stage there is usually less than 4 per cent infection, which greatly minimizes the danger of leaving sick seedlings. Since determination can easily be made as to whether a six-leaf seedling is healthy or diseased, based upon the condition of the petioles, the possibility of leaving sick seedlings is practically eliminated. Healthy six-leaf seedlings and both healthy and sick two-leaf and four-leaf seedlings have straight leaf petioles, whereas diseased seedlings having six or more leaves have bowed leaf petioles. Employment of this method which involves primarily delay in thinning, elimination of seedlings with bowed leaf petioles, and permitting the largest healthy beet to remain as a single offers a practical means of control and entails no extra operating expense.

Vacuolar changes in diseased cells. J. DUFRENOY.

The bulk of the plant cell is normally made up of one or a few large vacuoles, originating from the numerous smaller vacuoles of the meristematic cell swelling and fusing together as the cell ages. That evolution in the vacuolar system may be reversible is evident in healthy glandular cells and in many diseased cells where the breaking down of large vacuoles into a number of smaller ones seems to be a frequent occurrence. After staining portions of leaf epidermis in the living condition with neutral red, or staining with haematoxylin or acid fuschin after proper killing, clusters of small vacuoles around invading hyphae of *Puccinia* may be seen in *Arisaema*, and similarly in cells around hyphae of *Puccinia asphodeli* in cells of *Asphodelus subalpinus*. Clusters of small vacuoles, surrounded by deeply staining cytoplasm, are also conspicuous in cells of discolored areas of mosaic-infected plants.

In any case, the breaking down of large vacuoles into smaller, spherical or thread-like vacuoles is suggestive of a local proteolytic process.

Studies on the influence of environment on infection by certain bacterial plant parasites. A. J. RIKER.

In certain diseases where the pathogen penetrates the host through natural openings, the moisture condition of the plant previous to inoculation has been found to be very important in relation to the amount of infection secured. Experiments have been conducted upon the various host plants of the following pathogens: *Bact. lachrymans* Smith and Bryan, *Bact. pisi* (Sack.) E. F. S., and *B. tabacum* Wolf and Foster. In each case it was found that plants placed a day in a moist chamber previous to inoculation and then placed again in a moist chamber developed a great many more lesions than plants which were given the moisture treatment only after inoculation.

Temperature was also found to be important in the development of infection. The optimum, as measured by the size of lesions on the respective host plants, was found to be approximately 24° C. for *Bact. lachrymans*, 28° for *B. tabacum*, 12° for *Bact. holci* Ken., 28° for *Bact. coronafaciens* Elliott, and 28° for *Apl. michiganense*, E. F. S.

The maturity of inoculated leaves appears to influence both the number of infections and the size of the subsequent lesions. It has been observed in certain cases that the newly expanded leaves commonly developed more lesions than older leaves.

Seed infection by Bacterium phaseoli. W. J. ZAUMEYER.

Bacterium phaseoli causes a systemic invasion of the bean plant under certain conditions, as shown by Burkholder and others. Recent studies have shown that at times, the organism may pass into the developing seed through the vascular system of the plant, without the production of any visible macroscopic symptoms. From dorsal suture infection of the pod, the bacteria invade the funiculus, passing through the raphe into the seed coat. Entrance may also be made through the micropyle of the seed when the bacteria invade the pod cavity. They may enter the pod cavity either through the stomata of the pod or by breaking through the vascular tissue of the pod sutures. In the seed coats the bacteria traverse the intercellular spaces which are very large and afford an easy passage for the rapid migration of the pathogen throughout these tissues. Later they are found surrounding the cotyledons, but penetration into these structures before germination has never been observed. At the time of germination with the imbibition of water the seed swells rapidly and many of the epidermal cells of the cotyledons are pulled apart with the formation of natural rifts. It is through these tissue tears that the bacteria enter and penetrate into the cotyledons. This later results in the systemic invasion of the developing seedling.

Studies on bacterial pustule of soy bean. S. G. LEHMAN.

The presence of a pustular outgrowth has been emphasized as the chief diagnostic character by which the lesions of bacterial pustule may be distinguished from those of other bacterial diseases of the soy bean. In numerous instances the writer has isolated the organism of bacterial pustule (*Bacterium phaseoli* var. *sojense*) from lesions devoid of any vestige of pustular outgrowth. Other organisms isolated from the same lesions failed to infect soy beans in the inoculation tests.

Bacterial pustule disease was produced when the source of inoculum was diseased leaves kept air dry in the laboratory for nine months or diseased leaves which had been subjected to weathering and attendant decay for three months.

Seed treatment with a large number of dusts and disinfecting solutions have failed to control the disease. Tests in which a large number of varieties of soy bean were repeatedly inoculated artificially, both in the greenhouse and the field, showed the variety Columbia to be most highly resistant.

Bacterial spot of radish and turnip. HAROLD E. WHITE and M. W. GARDNER.

A bacterial spot disease of radish and turnip was found in Indiana in 1928. Abundant spotting occurred on the leaf blades, petioles, stems, and seed pods of radish. Bacteria forming similar yellow colonies were isolated from the two host species, and seedlings of both became infected in the greenhouse as a result of cross inoculations. The petiole lesions on radish were very destructive. Evidence of transmission on radish seed was obtained. In greenhouse inoculation tests the organism also infected cabbage, brussels sprouts, cauliflower, mustard, and tomato.

Migration of Bacterium tabacum through the leaf tissues of Nicotiana tabacum. J. BEN HILL.

The migration of *Bacterium tabacum* Wolf and Foster, the causal organism of wild fire, has been studied in the leaf tissues of the host, *Nicotiana tabacum*. It has been found that the bacteria migrate as zoogloeae from the region of the inoculation puncture, and penetrate the intercellular spaces of the uninjured host tissues. The form of the zoogloeae is determined largely by the shape of the intercellular space penetrated. This is in accord with the observation of the zoogloeae of other bacterial phytopathogens which have heretofore been studied. In the early stages of migration the zoogloeae pass along through the intercellular spaces, often almost surrounding some of the mesophyll cells but frequently causing no apparent injury to the protoplast. Vessels when injured seem often to be penetrated by the bacteria. The rate of migration of the bacteria, as expressed by the growth of the zoogloeae, is extremely slow when compared with that of the crown-gall organism (*Bacterium tumefaciens*) and is much slower than that of the fire-blight organism (*Bacillus amylovorus*). Few zoogloeae were observed in microscopic preparations made of the tissues less than 48 hours after inoculation. Preparations made three days after inoculation showed many zoogloeae.

The chromosome number in crowngall and cancer tissues. MICHAEL LEVINE.

This report includes the results of my studies of the chromosome numbers in crowngall cells of *Beta vulgaris* and *Nicotiana glutinosa*, in human epithelioma, and in mouse carcinoma No. 180. The cells in the reduction divisions in the beet show 9 chromosomes, while in the vegetative divisions only 18 chromosomes are found. In the crowngall tissue some cells show 18 chromosomes while many other cells contain 36 chromosomes. In a small percentage of cells approximately 72 chromosomes are to be seen.

In *N. glutinosa* the somatic divisions show 24 (diploid) chromosomes. This number is commonly found in dividing cells of crowngall tissue on this plant, although the tetraploid number (48) frequently occurs. Cells with still larger numbers of chromosomes have been observed, although I am not certain as to the exact count.

In human cancer a complete count of the chromosome number in giant cells is difficult. In a number of cases I found over 200 chromosomes. In spermatogenesis of the white mouse, 20 chromosomes may be counted in the primary and secondary spermatocytes. In transplanted mouse tumor cells, 40 chromosomes appear frequently, while cells with larger numbers of chromosomes are common.

The polyploid cells seem to originate through the failure of the cell to divide after nuclear division.

Studies on the bacteriological differentiation of the crowngall and hairyroot types of bacteria. W. H. WRIGHT, A. J. RIKER, H. E. SAGEN, and W. M. BANFIELD.

A comparison of the crowngall (*Bact. tumefaciens* Smith and Town.) type of organism with the type which causes hairyroot has been made from the standpoint of

both their morphological and physiological characters. A number of strains (isolations from different sources) were employed which were purified by special means; and, in the case of crowngall organisms, cultures of single-cell origin were used as a basis of comparison. The crowngall and hairyroot organisms have been found to differ in regard to the following characters: (1) motility; (2) growth, absence of growth, and growth characters in nine different synthetic media; (3) carbohydrate fermentation, including differences in true acidity (pH) and titrateable acidity, of xylose, arabinose, glucose, galactose, mannose, lactose, maltose, rhamnose, and erythrotol; (4) action on litmus milk; (5) absorption of congo red; and (6) serological properties. The data now available appear to indicate that strains of unquestioned purity of the typical crowngall organism possess many properties which are different from those of the hairyroot organism. These, when correlated with the distinct kinds of response of the host plants to the invasion of the pathogens, strongly suggest differentiation of a specific rank.

Studies on the differentiation of the crowngall type of bacteria from non-pathogenic bacteria of the radiobacter group. WILLIAM H. WRIGHT, A. J. RIKER, and H. E. SAGEN.

The striking similarity of pure cultures of the typical crowngall organism (*Bact. tumefaciens* Smith and Town.) and *B. radiobacter* Beij. is readily apparent when they are compared. Because both microorganisms may be abundant in the soil and present in or on material used for the isolation of cultures of the crowngall organism, their cultural differentiation without resorting to plant inoculation is desirable.

The two microorganisms have been found to differ in respect to these characters: (1) motility, (2) morphology, (3) absorption of dyes, (4) growth on glycerophosphate media, (5) reduction of nitrates, and (6) serological properties. The crowngall and radiobacter types are very similar in many of the characteristics where the crowngall and hairyroot organisms are different. An effort is being made to discover a satisfactory cultural means of differentiation.

Potency and specificity of a lytic principle (bacteriophage) obtained from Pseudomonas tumefaciens. J. H. MUNCIE and M. K. PATEL.

A lytic principle has been obtained from a pure culture of *Ps. tumefaciens* (V) and also from an artificially induced gall on sugar beet (III). The potency of the lytic principle in each case has been increased until, after 17 filtrations, "phage" V at a dilution of 10^{-34} and "phage" III at 10^{-30} dilution cause lysis of a 24-hour-old broth culture of *Ps. tumefaciens*. Cultures of *Ps. tumefaciens* failed to produce infection on tomato plants, after being subjected to the action of the bacteriophage for nine hours. The lytic principle survives 10 minutes' heating at 80° C. but is inactivated at 85° C.

When tested against 20 strains of *Ps. tumefaciens* from various hosts and eight other bacterial plant pathogenes, "phage" V was found to be specific in its lytic action, affecting only the strain of the crown-gall organism from which it was developed.

Some researches on Pseudomonas tumefaciens. M. K. PATEL.

Immune serum produced against *Pseudomonas tumefaciens* (raspberry strain) by injections of a rabbit agglutinated the homologue up to and including a titre of 1–12800, but not the crown-gall organisms obtained from peach (*Prunus persica*), apple (*Pyrus malus*), geranium (*Pelargonium hortorum*), walnut (*Juglans nigra*), rose (*Rosa odorata*), sand cherry (*Prunus besseyi*), and incense cedar (*Libocedrus decurrens*). The raspberry strain inoculated into weeping willow (*Salix babylonica*) and isolated after more than three months was not distinct from the original strain in agglutination tests. The agglutinable and inagglutinable pathogenic strains of *Ps. tumefaciens* were not affected by

a passage through tomato plants. The crown-gall organism seems to survive passage through the blood stream of rabbits and the intestinal tract of mice and guinea-pigs.

Further agglutination tests with phytopathogenic bacteria. GEORGE K. K. LINK, A. E. EDGECOMBE, and J. G. GODKIN.

The experimental procedure was essentially that reported by Link and Sharp (Bot. Gaz. 83, 1927) and Link and Link (Bot. Gaz. 85, 1928). In addition, absorption of agglutinins was carried out with antisera and suspensions of some of the organisms.

Tests for normal agglutinins were negative. Titres up to 1–10,240 were obtained. The following serological relationships are indicated: *Bact. campestre* is very closely related to *Bact.* X (horseradish pathogen, Lucia McCulloch), less closely to *Bact. cucurbitae, Bact. phaseoli,* and *Bact. translucens; Bact.* X, very closely to *Bact. campestre,* and only distantly, if at all, to the others; *Bact. cucurbitae,* distantly only to *Bact. translucens* var. *undulosum; Bact phaseoli,* closer to *Bact. curcubitae, Bact. translucens,* and *Bact. translucens* var. *undulosum* than to *Bact. campestre; Bact. pruni,* very slightly to only *Bact. cucurbitae* and *Bact. translucens* var. *undulosum; Bact. translucens,* only and only distantly, if at all, to the others; *Bact. cucurbitae,* distantly only to *Bact. translucens* var. *undulosum,* closely to *Bact. translucens* and *Bact.* Z, and very slightly to *Bact. phaseoli; Bact.* Z, very closely to *Bact. translucens* var. *undulosum* and not at all to the others. Data were inconclusive for *Bact.* Y (poppy pathogen, M. R. Bryan).

Physiological studies of Bacterium translucens and Bacterium translucens var. undulosum. JAMES GODKIN.

Bacterium translucens attacking barley and *Bacterium translucens* var. *undulosum* attacking wheat, barley, and rye differ somewhat when grown on agar. Colonies of both organisms when grown on an agar medium (pH 6.8) are circular, smooth, shining, and 1–5 mm. in diameter. The colonies are waxy yellow and have irregular concentric striations within them. Margins are apparently always entire. These descriptions correspond to those given by Jones, Johnson, and Reddy for *Bacterium translucens.* Undulations within the colonies described by Smith for *Bacterium translucens* var. *undulosum* appeared in colonies of both organisms. In *Bacterium translucens* var. *undulosum,* these undulations appeared in 9 days, while in *Bacterium translucens* they appeared in 12 days. They are more pronounced in *Bacterium translucens* var. *undulosum.* In both organisms these undulations seem to disappear in old colonies. No differences were noted when the organisms were grown on potato dextrose and beef-bouillon. No reduction of starch occurred for either organism. *B. subtilis,* used as a check, showed starch reduction. Both organisms produced acid in beef-bouillon plus dextrose, galactose, levulose, and sucrose. In beef-bouillon plus lactose, *Bacterium translucens undulosum* produced an acid reaction, while *Bacterium translucens* produced an alkaline reaction. In beef-bouillon plus maltose both organisms at first produced an alkaline reaction, but later an acid reaction which was more pronounced with variety *undulosum.*

The basal rot of narcissus bulbs caused by Fusarium sp. FREEMAN WEISS.

Though long known to growers, this disease has not received a scientific description. It has caused great losses in planting stock and to bulbs in transit and storage. Affected bulbs suffer immediate decay or may be planted only to rot in the ground or produce feeble, barren shoots. Basal rot was particularly destructive in Virginia and Long Island, N. Y., in 1928.

The prevailing horticultural opinion ascribes this disease to unfavorable conditions during harvesting and storage, admitting to the fungi found in affected bulbs only a

weakly parasitic rôle. Field studies have shown, however, that infection of the roots and basal plate may begin in the field. Subsequent handling and storage conditions only modify the course that this infection takes. Under accepted operating methods losses up to 50 per cent in certain varieties are sustained even by experienced growers.

Typical specimens from all the principal narcissus centers of the United States and from Holland consistently yield a *Fusarium* which belongs to the section Elegans but which is not identified with any described species. Its pathogenicity for narcissus, but for no other flowering bulb or onions, has been repeatedly proved. Injuries favor but are not indispensable to infection. Varieties differ in susceptibility to basal rot.

The relation of the hot-water treatment of narcissus bulbs to basal rot. FREEMAN WEISS.

The hot-water treatment of narcissus against eelworms and bulb flies consists of immersing the bulbs for 2½ hours in water at 110° F. Treatment is required of all narcissus imported into the United States, but cyanide fumigation may be substituted in the case of domestic stocks where fly infestation only occurs.

In this process bulbs affected by Fusarium rot and healthy bulbs are frequently mingled; hence spores and hyphal fragments from the superficial mycelium which develops on affected bulbs may be liberally introduced into the water.

Tests have shown that microconidia of this *Fusarium* retain their viability in water at 110° F. for at least 8 hours. In sweet-potato decoction survival is curtailed and does not exceed 4 hours. Mycelium retains the ability to grow after similar exposure for at least 24 hours. Thus the treatment and subsequent handling may multiply basal-rot infection, a condition frequently realized in practice.

Either the subsequent handling must be such as to suppress infection, such as immediate planting in cool soil, or a fungicide should be introduced into the water to prevent contamination of healthy bulbs. Tests with a number of hot fungicidal treatments show this method to be practicable without injury to the bulbs.

Wire-screen fences for the control of aster yellows. L. O. KUNKEL.

During the past season an attempt was made to control aster yellows by means of screen fences. Adults of the leafhopper *Cicadula sexnotata*, which spreads yellows, are unable to pass through wire screen having 18 meshes to the inch. Such screen was used to fence each of four garden plots 25 feet long and 10 feet wide. The fences, which were 4, 5, 6, and 8 feet high, respectively, were built in the spring before the leafhopper appeared. During the first week of June 45 healthy aster plants were transplanted to each plot. Plants that died were replaced by healthy ones. Yellowed plants were removed from the fenced area as soon as observed. Unfenced aster plantings served as checks.

About one-third of the check plants were yellowed when the disease first appeared in the fenced areas on August 13. Between this date and September 16, when the experiment was ended, only 20 per cent of all fenced plants had contracted yellows, whereas 80 per cent of the check plants were diseased. Under the conditions of the experiment here described, careful rogueing of fenced plots gave fairly satisfactory control of aster yellows.

Wilt-resistant asters. L. O. KUNKEL.

Five strains of the China aster, bearing flowers in a variety of colors and resistant to aster wilt, were grown on plots of aster-sick soil at Yonkers, N. Y. The plots were inoculated four years ago by working compost made from wilted aster plants into the soil. Asters have been grown on the plots during the past five years. The severity of

wilt has continually increased. There was 100 per cent loss from wilt in several commercial varieties during 1928. Four strains grown from seed selected by Mr. D. G. Milbrath and one strain of a commercial variety proved to be very resistant on these plots. There was some loss from wilt in each of the five strains, but they all yielded a good crop of flowers. Seed has been selected from the most resistant plants in each strain. It is hoped that they may be still further improved.

Progress with the control of aster wilt and yellows. L. R. JONES and REGINA S. RIKER.

Selections for resistance to aster wilt, reported upon last year, have been continued with encouraging results. The selections from the favorite red variety, Heart of France, annually tested and reselected since 1925, are apparently stabilized with a high degree of resistance. In the Late Branching type, resistance has also been more readily secured with red than other colors, suggesting association of resistance with this pigmentation. Almost equally promising strains include lavenders and rose, and good beginnings have been made with this and other types in white, pinks, purples, etc.

Previous trials employed small cheesecloth-covered cages to prevent yellows. This year, in trials on a larger scale, a method comparable to shade culture of tobacco was successfully adopted. Hopper-proof cloth-covered inclosures (30 x 100 feet) proved practicable under Wisconsin climatic conditions. Of the tobacco cloths only the finest (22 threads an inch) was effective. Probably slightly coarser, stronger cloths can be specially adapted for hopper exclusion. Since these shaded asters developed superior cut flowers under commercial trials this year, certain commercial florists purpose trying such cloth-shade culture next year.

Iris rust, Puccinia iridis. E. B. MAINS.

Rust from *Iris fulva* has been studied on 14 species of *Iris* which have been listed as hosts. Of the Apogon section of the genus *Iris, I. fulva, I. spuria, I. foliosa,* and *I. missouriensis* were susceptible; *I. ochroleuca* was moderately resistant; and *I. graminea, I. tenax, I. versicolor,* and *I. pseudocorus* were practically immune. The distantly related *I. xiphium* and *I. xiphioides* of the Xiphium section were very susceptible, while *I. dichotoma* of the Pardanthopsis section was moderately susceptible, and *I. tectorum* of the Evansia section and several varieties belonging to pallida and Germanica types of the Pogoniris section were practically immune.

A collection of the rust from the variety Dorothea K. Williamson and another from *Iris versicolor* were found to be physiologically distinct, since *I. fulva* was highly resistant to both of these. *Iris versicolor* is not uniform in its susceptibility to the rust collected on it. A number of plants collected in the immediate vicinity of the susceptible plants proved to be resistant or practically immune.

Anthracnose of the snowberry (Symphoricarpos albus var. laevigatus). W. H. DAVIS.

Diseased fruits were observed on snowberry plants on the campus of the Massachusetts Agricultural College in September. In October, 60 per cent of the fruits had become infected. Examination of diseased fruits showed the presence of acervuli and numerous conidia of a *Gleosporium* (?) sp.

The fungus was isolated, cultured, and Koch's rules of proof fulfilled. When conidia were spread on both punctured and intact surfaces of the fruit, infected areas developed which showed as a wash of cinnamon-rufous color which later turned to shades of hazel, and 5 to 9 days afterwards were dotted with small flesh-colored flecks, acervuli bearing conidia in a manner characteristic of the disease.

In cultures on potato-dextrose agar the floccose mycelium varied from a light mineral to a smoky gray, grew rapidly, and produced dark flecks, the acervuli, with conidia 1 to 2 mm. above the agar surface.

The fungus is described as follows: *Acervuli:* mostly subcutaneous, erumpent, solitary to confluent; width, 100 μ: length, 60 μ (20 measured). *Conidiophores:* Unequal hyaline, unbranched, perpendicular, subclavate, fasciculate, 2 × 20 μ (20 measured). *Conidia:* terminal, cylindrical, apex rounded, hylum slightly protruding, nonseptate, hyaline; limits, 4.5–7.2 × 12.6–20 μ; standard, 5.4 × 16 μ (50 measured); contents, granular, with an opaque area (nucleus) near the center.

Further studies of privet anthracnose. A. J. MIX.

A privet whose botanical relationships are unknown is being offered by nurserymen under the name "Lodense." It was reported to the writer by H. W. Anderson as susceptible to anthracnose. Results of inoculations using *Glomerella cingulata* from privet and apple justify the following conclusions: 1. "Lodense" privet is as susceptible to anthracnose as is European privet (*Ligustrum vulgare*) and must be considered unsuitable for hedge planting wherever the disease occurs. 2. *Glomerella cingulata* from apple is pathogenic to both these privets, but much less so than is *G. cingulata* from privet.

A considerable series of inoculations of apple branches were made with the fungus from both apple and privet. None of these resulted in infection.

Parasitism of Conopholis americana Wallr. on roots of Quercus bicolor Willd. K. D. DOAK.

The growth of *Conopholis americana*, a non-chlorophyllous phanerogamic parasite on roots of *Quercus bicolor*, resulted in a gall-like structure composed largely of parasitic tissue. Sections taken through the gall demonstrated that the glandular, easily separated groups of storage cells of the parasite were enclosed by connective tissue in which lignified conducting vessels were found. At the point of contact between parasite and host tissue, frenate extensions of normal xylem vessels of the latter were found extending into the gall to a distance of 10–12 mm. In each gall examined there were more than 15 such extensions, less than one-half of which coiled backward to form slightly clubbed tips. Abnormal arrangement of host cells occurred in these clubbed projections. Intracellular absorbing organs of the parasite were not present in host cells at the region of direct contact. Cell-sap concentration was found to be least in the host tissue, with sucrose as a plasmolyzing agent. Bacterial or fungal symbionts were not present in these galls.

Biologic control of the aphids Rhopalosihum persicae Sulzer and Aphis gossypii Glover. J. A. B. NOLLA.

Laboratory and field experiments have shown that the aphids which feed on eggplants, peppers, and cucumbers can be effectively controlled by means of the fungus *Acrostalagmus aphidium* (determined by Vera K. Charles, Bureau of Plant Industry, Washington, D. C.). A spore suspension was sprayed on a field of eggplants heavily infested with aphids. This resulted in death of the majority of aphids. Experiments under controlled conditions were made with healthy colonies of the aphids feeding on eggplant, cucumber, and pepper plants, which were sprayed with a spore suspension of the fungus. The method is very cheap and can be applied with great advantage under favorable conditions of humidity.

Further results of oat-smut control in Ohio. A. L. PIERSTORFF and J. D. SAYRE.

In 1927 formaldehyde dust was introduced for the control of smuts of oats. This year, through the Extension Department of the Ohio State University and the Ohio

Agricultural Experiment Station, more data have been obtained on its use under different conditions. Farm demonstrations were conducted where its use under actual farm conditions were shown. The results of these tests on the control of oat smuts in fields of grain were obtained. The Experiment Station continued tests on a smaller scale in the greenhouse and in the field. Different methods of treating the grain and various concentrations of the dusts were used at three dates of planting. The results led to the following conclusions: that a 5 per cent formaldehyde dust at the rate of about 3 ounces per bushel of grain is most effective; that the treatment need not be made in a closed container; and that the grain should be left in sacks over night before sowing.

The rôle of humidity in the life cycle, distribution, and control of the loose-smut fungus of wheat. V. F. TAPKE.

The wheat varieties, Little Club, Jenkin, and Washington Hybrid 128, when continuously grown in the Pacific Coast States, rarely contain loose smut, but these wheats proved extremely susceptible when the flowers were artificially inoculated in a humid greenhouse at Arlington Experiment Farm, Rosslyn, Va. The loose-smut fungus of wheat infects only through the flowers of its host. At infection time the relative humidity of the atmosphere in the Pacific Coast States usually is very low. Through the use of chambers with definite relative humidities it has been found that the spores do not germinate within the flowers at the low humidities which normally prevail on the Pacific Coast when the wheats are in bloom, thus preventing infection. The flower-infecting loose smuts of oats and barley as well as the loose smut of wheat are rarely found in those sections of the country where the atmosphere at flowering time is very dry, although the host is widely grown. Loose smut in wheat grown on irrigated land was reduced but not controlled by withholding water at flowering time.

Studies of certain soil phases of the wheat take-all problem. HURLEY FELLOWS.

Experiments have shown that *Ophiobolus graminis* is present to a depth of at least 10 inches in infested soils in Kansas. However, in inoculation experiments, the most severe infections resulted when inoculum was placed only one inch below the crowns of the wheat plants. When the inoculum was placed 4 or more inches below the crowns, the wheat plants were uninjured.

Experiments have shown that inoculum of *Ophiobolus graminis* grown on a mixture of autoclaved oats and barley soon loses its virulence when the entire culture is added to uninfested soil. Each of several kinds of organic matter such as chicken manure, horse manure, alfalfa stems and leaves, boiled barley-oat mixture, and potato flour added separately to infested soil, both in greenhouse and field, greatly reduced severity of take-all. In some cases almost perfect control was obtained. (Cooperative investigations between Kansas Agricultural Experiment Station and Office of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture.

Some chemical and morphological phenomena attending infection of the wheat plant by Ophiobolus graminis Sacc. HURLEY FELLOWS.

Ophiobolus graminis penetrates directly through the epidermis of the roots and subcoronal internode and coleoptile of the wheat plant. The crown becomes infected through the subcoronal internode. All portions of the tissue attacked may be invaded.

Certain cell walls in the vicinity of the invading parasite become thickened or produce elongated protuberances in front of and around the invading hyphae. These structures, previously undescribed, are given the name "lignitubers." The xylem walls of the subcoronal internode may become so thickened that plugging occurs. In the

coleoptile, the thickenings occur mostly in the epidermis while in the roots they are scattered promiscuously.

Other cells, however, are completely disintegrated. This is especially true of phloem and adjoining cells. With the exception of the xylem, the entire stele of the roots may be disintegrated.

Microchemical studies show a non-uniform reduction of cellulose in diseased roots. The cellulose loss is replaced by lignin and a slight amount of suberin. This is true especially of the thickened walls and the "lignitubers." Other substances are not changed by the invasion of the fungus. (Cooperative investigations between Kansas Agricultural Experiment Station and Office of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture.)

Relative susceptibility of various varieties of sorghum to rust, Puccinia purpurea. E. B. MAINS.

Greenhouse and field tests of several varieties of sorghum at Lafayette, Indiana, during 1928 showed marked differences in the reaction of varieties. All varieties of the Sorgo group included in the experiment were more or less susceptible, differing principally in the number of uredinia developed. Dwarf Sumac, Fielding Sumac, and Red Amber proved very susceptible; and Leoti Red, Freed, White African, and Kansas Orange were moderately susceptible. Of the grain sorghums, all of the five strains of Feterita tested were very susceptible. Of the Kafirs, Red Kafir and Sunrise were very susceptible, Dawn was moderately susceptible, and Blackhull and Reed were moderately resistant. All five of the strains of Milo were very resistant, showing only small purplish spots with an occasional small uredinium. Two strains of broomcorn and two of Hegari were moderately susceptible. A line of Dwarf Shantung Kaoliang and one of Shallu showed considerable resistance, especially in the field. Infection of almost all of the lines, resistant as well as susceptible, produced a purpling of the infected areas. One variety, the susceptible Leoti Red Sorgo, was outstanding on account of the absence of purple in infected spots. (Cooperative investigations between the Purdue Agricultural Experiment Station and the Office of Cereal Crops and Diseases, Bureau Plant Industry, U. S. Department of Agriculture.)

Preliminary results from cross inoculation and culture studies upon the fungus Rhynchosporium secalis (Oud.) Davis causing scald of cereals and other grasses. RALPH M. CALDWELL.

The organism *Rhynchosporium secalis* (Oud.) Davis which causes scald of barley, rye, and other grasses, has been isolated from five different hosts growing in the vicinity of Madison, Wisconsin, and successfully grown in culture. Besides the cereals, barley and rye, isolations have been made from the grasses, *Agropyron repens*, *Bromus inermis*, and *Hordeum jubatum*. The last named plant has not previously been reported as attacked by this fungus. Single spore cultures of the fungus from barley are distinct from those from rye in pigmentation, type of growth, and relative abundance of conidia, these characters being very constant.

Oderbrucker barley, Schlansted rye, and Marquis wheat have been inoculated with these single-spore cultures by atomizing conidial suspensions over the leaves of seedling plants. Infection was secured only in cases where the plant inoculated was the host from which the culture had originally been secured. Very typical lesions were obtained where this was the case. Similarly, only barley became infected where overwintered diseased barley leaves were used as a source of inoculum.

It seems quite evident that barley and rye in the vicinity of Madison, Wisconsin, are each attacked by a distinct physiologic form of this fungus.

Further studies on Penicillium injury to corn. HELEN JOHANN.

Various pedigreed strains of dent corn in the field at Bloomington, Illinois, and Madison, Wisconsin, in the summer of 1928, showed marked reduction in stand and yield following inoculation at time of planting with a spore suspension of *Penicillium oxalicum*. Symptoms in the field were similar to those previously reported in the greenhouse.

The parasite is not aggressive enough to enter vigorous, living cells. Sections through lesions indicate that a toxic substance injures or kills the cells in advance of the fungus. Oxalic acid produces similar lesions when applied to the surface of the seedling. Yellowing and drying of leaves, symptoms of the Penicillium disease, were also reproduced by placing young seedlings in dilute solutions of oxalic acid.

Chemical analysis disclosed the presence of considerable quantities of oxalic acid in corn-seedling decoctions on which *P. oxalicum* had grown for six days at 20° C.

The fungus is chiefly intercellular, and not confined to any particular tissue. In the most severely injured seedlings it was found in the region of the cotyledonary plate. The hyphae entered by working their way between the cells of the root tip, through the depleted scutellum, the ruptured coleorhiza, root ruptures, or injured tissue of any sort. (Cooperative investigations between the Office of Cereal Crops and Diseases, Bureau of Plant Industry, United States Department of Agriculture, the Wisconsin Agricultural Experiment Station and Funk Brothers Seed Company.)

Reaction in agronomic strains of timothy to Ustilago striaeformis (Westd.) Niessel. W. H. DAVIS.

An investigation was undertaken to answer the following: 1. Are some agronomic strains of timothy (a) susceptible to *Ustilago striaeformis*, (b) resistant, or (c) immune? 2. Are there physiologic forms of the fungus parasitizing this host?

Timothy seeds were collected from the following number of stations: in Wisconsin, 4; New York, 3; Iowa, 2; Connecticut, 1; Massachusetts, 8; New Hampshire, 1. Agronomic strains 4081, 4001, 4123, 4003, 4031, 4078, 4079, 4059, 1777, 1676 were supplied by Dr. C. H. Meyers, of Cornell.

The spore materials were collected from: (1) 5 field stations in Massachusetts, 2 in Connecticut, and 1 in New York; (2) infected timothy plants which had been inoculated with spores collected at stations in Wisconsin and New York.

Infected plants were observed among partly matured, inoculated plants, the seedlings of which had been cultured from seeds collected at each of the field stations and in each agronomic strain. The agronomic strains were arranged in order of their resistance beginning with the least resistant: 4079–R1, 1676–R2, 4123–R3, 4001–R4, 1777–R5, 4081–R6, 4003–R7, 4078–R8, 4031–R9, 4059–R10. Artificial infections varied from 70 to 1 per cent. No agronomic strains of timothy were found immune to the spore form of *U. striaeformis* used, and no physiologic strains of the fungus were detected.

Studies of cold resistance and susceptibility in corn. J. R. HOLBERT and W. L. BURLISON.

Wide variations in resistance to injury from cold in the fall have been found to exist in inbred strains of corn, in recombinations of inbreds, and in commercial open-pollinated strains, as they approach maturity. Some inbreds were killed by a few hours exposure to temperatures ranging from 45° to 50° F. Many inbreds, recombinations, and commercial strains were injured or killed by a succession of cold nights during which temperatures ranged from 45° to 33° F. Other inbreds and recombinations withstood six hours of 32° to 30°, and a few others withstood 28° F. for hours. These differences have been observed under natural conditions for the past five years and some of them were found under accurately controlled artificial conditions in the field in 1928.

In the spring of 1925, when field temperatures dropped below 32° for several hours, reaching as low as 25° F., a few inbreds and recombinations, 4 to 6 inches high, escaped without apparent injury. Under the same conditions many other strains were severely injured and some never recovered from the injury.

Seed, matured on plants high in cold resistance, produced plants more resistant to seedling blights, lodging, and stalk breaking than did seed gathered at the same time from corresponding plants previously injured by cold. (Cooperative investigations between Illinois Agricultural Experiment Station, Funk Brothers Seed Company and the Office of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture.)

Mutation in Ustilago zeae. E. C. STAKMAN, J. J. CHRISTENSEN, and W. F. HANNA.

Ustilago zeae is very unstable genetically. Mutation occurs with surprising frequency in some monosporidial lines, which apparently are haploid clones; while it occurs but rarely in others. During a period of 9 months, about 100 different mutants were produced by one line and more than 70 by another. That these mutants are not mere temporary phenotypes is shown by their constancy; that they are not the result of normal segregation is indicated by cytologic and genetic studies. The mutants differ from their parents and each other in one or more of the following respects: morphology, cultural characters, and apparently sometimes in sex—therefore, in potential pathogenicity. The frequency of mutation can be influenced by certain environmental conditions, and suitable media sometimes are necessary to bring out the differences between the mutants.

Calcium monosulphide, a substitute for lime-sulphur for summer spraying. R. H. HURT.

Experiments conducted on Winesap apples for the past three years have shown that calcium monosulphide is as efficient as lime-sulphur in the control of fungous diseases of apples and is much more safely and easily used. Calcium monosulphide has caused no injury, whereas lime-sulphur and bordeaux mixture caused severe injury to foliage in adjoining plots. It also gave a better finish to the fruit.

In the 1926 and 1927 experiments calcium sulphide U. S. P. containing approximately 60 per cent calcium monosulphide was used at the rate of 12½ pounds to 50 gallons of water. In the 1928 trials, a commercial preparation containing approximately 65 per cent calcium monosulphide was used at the rate of 10 pounds to 50 gallons of water.

When calcium monosulphide was used as a complete summer spray the average scab infection for the three-year period was 3.19 per cent. When lime-sulphur was used for the early summer applications followed by bordeaux mixture, the average scab infection for the three-year period was 7.40 per cent. The three-year average of scab infection in the checks was 75.33 per cent.

A promising spray for the control of peach bacterial spot. JOHN W. ROBERTS and LESLIE PIERCE.

In southern Indiana a spray composed of zinc sulphate 4 lbs., hydrated lime 3 lbs., casein lime ½ lb. or zinc sulphate 4 lbs., hydrated lime 4 lbs., alum (aluminum ammonium sulphate) 1½ lbs. to water 50 gals., has checked infection of the peach by *Bacterium pruni*. In 1928 six applications were made at intervals of two weeks beginning at petal-fall. Care was taken to cover fruits and the underside of leaves. Spotting of leaves and defoliation were markedly less on these trees, and the leaves were a deeper green and larger than those of trees sprayed or dusted with sulphur.

The number of infected fruits was not greatly reduced but the number and size of infections were much less. From the zinc plats 9 and 17 per cent respectively of

the fruit were culled because of *Bacterium pruni* infections, and 27 per cent from the unsprayed plat. Less than 1 per cent of the unsprayed fruits was wholly free of infection while in the zinc plats 10 and 5 per cent were free respectively.

Used alone, the zinc sprays caused no noticeable injury, but the addition of arsenate of lead caused injury enough to suggest caution.

Phony disease of the peach. LEE M. HUTCHINS.

Phony disease of the peach is a communicable disease, the cause of which is not definitely determined. The infective principle apparently resides only in the roots, and the incubation period is about 18 months. Since its first recorded observation at Marshallville, Ga., about 50 years ago, phony disease has spread until at the present time it occurs in the districts that produce 90 per cent of the commercial peach crop of Georgia. It has recently appeared also in eastern Alabama. Phony trees produce short terminal growth, profuse lateral branching, and deep green foliage. Trees never recover from the phony disease, neither do they die of it, but live on for many years. Economic losses are due to a marked dwarfing effect and to a decrease in the average size of the fruits and in the number of fruits per tree. After a few years of the disease phony trees bear few if any marketable peaches. Extensive investigations with a view to developing control measures based on the selection of resistant stocks are under way at the United States Peach Disease Field Laboratory, Fort Valley, Ga.

The relation of certain bacteria to the development of roots. A. J. RIKER, W. M. BANFIELD, and G. W. KEITT.

Root stimulation and the development of some types of "hairyroot" have been shown to follow inoculations with certain bacteria. These results have been obtained through continuation of studies (1) of malformations on apple nursery stock which were not prevented by the control measures used and (2) of certain organisms which closely resembled *Bact. tumefaciens* Smith and Town. in colony characters on agar media and which were found associated with certain overgrowths on apple. Hairyroot has followed inoculations through punctures in the underground parts of the current season's growth from apple grafts with approximately 40 strains (isolations from 40 sources) of bacteria isolated from overgrowths on apple. In the early stages overgrowths developed which were more or less conspicuous and from which fleshy roots appeared. In the later stages the fleshy roots may become fibrous. In some cases the enlargements at the bases of the root developments were quite conspicuous. Parallel inoculations with known *Bact. tumefaciens* resulted in typical crowngalls and in no case showed any stimulation of roots. From hairyroot induced by different inoculations, organisms have been repeatedly isolated which apparently are identical with those inserted. Inoculations with six reisolated strains have in turn produced hairyroot. Root stimulation has also followed inoculations on rose and honeysuckle.

Progress in freeing the virus of mosaic disease of tobacco from accompanying solids. C. G. VINSON and A. W. PETRE.

The virus of mosaic disease of tobacco may be precipitated from solution by means of an aqueous solution of safranin. The virus may be recovered by removing the safranin from the precipitate.

Material which gives an infectious solution when redissolved in water has been salted out of infectious juice with ammonium sulfate and also with magnesium sulfate.

Two volumes of acetone or alcohol, when added to one volume of juice from diseased plants, at about 0° C., throws down a precipitate containing practically all the virus.

Some of the phosphate, sulfate, and most of the protein and pigment may be removed from juice of diseased plants, with low concentrations of lead acetate and barium acetate without apparently removing or injuring the virus.

Cleared juice from diseased plants, concentrated in vacuo to 0.4 the original volume and brought to about 0° C. gives a precipitate when two volumes of acetate at −15° C. are added. This precipitate contains only about 10 per cent of the solids of the original juice, but apparently contains all of the original virus.

The virus behaved in many ways similar to a chemical substance.

The separation from mosaic tomato plants of toxins which produce some of the typical mosaic symptoms. H. R. KRAYBILL, P. H. BREWER, R. W. SAMSON, and M. W. GARDNER.

Tomato plants inoculated with a combination of the non-infectious filtrate (Kraybill and Eckerson, Amer. Jour. Bot. 14: 487–495. 1927) from diseased plants, which produced fern-leaf symptoms, and juice from potato tubers in no case produced the streak disease. Plants inoculated with the residue, which contains the tomato mosaic principle, and juice from potato tubers developed tomato streak disease. Numerous inoculations of tomato plants with the filtrate freed from the infectious mosaic principle have produced the fern-leaf-like symptoms. Repeated efforts to transfer by inoculation from these fern-leaf plants to healthy tomato plants have been negative. These filtrates have been heated for two and a half hours at 126° C. without any reduction in their activity. Frequently these tomato plants which show the fern-leaf-like symptoms produced by the non-infectious filtrates eventually outgrow these effects. Inoculations with filtrates prepared from healthy tomato plants have failed to produce these fern-leaf-like symptoms. The results show that the material in the filtrates which produce these fern-leaf-like symptoms is non-living, is of the nature of heat stable toxins, and is probably produced by the mosaic virus.

Purification and certain properties of the tomato mosaic virus. P. H. BREWER, H. R. KRAYBILL, and M. W. GARDNER.

Juice from mosaic tomato plants thoroughly ground in a food chopper is expressed through heavy muslin in a Cossette porcelain press, diluted with an equal volume of distilled water, and passed through a supercentrifuge three times. The liquid is discarded. The dark green gummy residue is scraped from the bowl of the centrifuge, resuspended in distilled water by stirring with a Bouyoucos deflocculator, and again passed through the supercentrifuge. To the liquid, which is somewhat yellowish and cloudy, aluminum gel prepared so as to have a slightly acid reaction is added. The mixture is filtered and the filtrate is a clear and colorless suspension of the virus apparently as active as the originally expressed juice of the plant. The aluminum gel removes the yellow color and the suspended solids. The longevity of the virus in this state at ordinary temperatures is less than two months. The virus is inactivated when, by the addition of NaOH, the suspension is made more alkaline than pH 7.7, and becomes active again at about the same point when HCl is added.

Progress report on cereal scab development during the season of 1928. JAMES G. DICKSON, E. B. MAINS and HELEN JOHANN.

Scab has again taken a great toll of small grains in the central states. The losses were greater in spring wheat, barley and oats than in 1919. In northern states large amount of damage was done by spread of the disease in shocks.

Clean, well plowed fields are good assurance against reoccurrence of an epidemic next year. Of wheat varieties tested, Norka, Progress, Resaca, and Illinois 1 have shown the greatest resistance to scab. (Cooperative investigations between Office of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture, and Wisconsin and Purdue Agricultural Experiment Stations.)